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THE INCANDESCENT LAMP AND ITS MANUFACTURE.

BY

GILBERT S. RAM.

W. Stuart-Smith
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INTRODUCTORY.

With the expiration of Edison's master-patent for the carbon incandescent electric lamp, the attention of electric light engineers, as well as of all those who use the light, is once more directed to the consideration of the lamp itself, to the possibility of obtaining better lamps, and to the probable reduction in price which will naturally follow. Owing to the long prevailing monopoly in the sale and manufacture, there has been little inducement for those interested to experiment and to study the problems connected with the incandescent lamp. As a result of this, the literature of the lamp is very scanty, and is entirely confined to the pages of the leading technical journals. While dynamos, alternators, transformers, arc lamps, and almost every piece of apparatus connected with electrical engineering and lighting, have been written on at length and discussed at meetings of scientific societies, the incandescent electric lamp, which has been the chief cause of the very existence of these machines and apparatus, has been comparatively neglected. With the exception of the valuable series of articles by Mr. Swinburne which appeared in *The Electrician* six years ago, no comprehensive or detailed account of lamp manufacture has appeared. The manufacture of the incandescent lamp and the principles underlying it are, consequently, but little known, except to those actually engaged in the work.

As a thorough understanding of the lamp and the possibilities of its improvement can only be obtained by considering the various processes of its manufacture, it is probable that a work on the subject at the present time will be welcomed by those who are interested therein and have not had the opportunity of studying it for themselves.

As writers in whose hands this most interesting subject might have fared better have not essayed to undertake the task, the Author asks the indulgence of readers for the many shortcomings which may be apparent to them. This indulgence will, he feels, be the more readily extended to him when those interested in the subject understand that "The Incandescent Lamp and Its Manufacture" does not profess to at all exhaust the subject, or to describe nearly all the processes of manufacture. All that is attempted is to give readers such information as the Author, in the course of a considerable experience in lamp-making, has acquired, and to place this information before them with as little mathematical embellishment as, under the circumstances, is possible.

CHAPTER I.

THE FILAMENT.

THE light-emitting portion or burner—called by Edison the filament—of the incandescent lamp, it is well known, is composed of carbon, which is raised to a state of incandescence by the passage through it of a current of electricity. Carbon is not the only substance which can be used. The number of possible materials is, however, very small, and for two reasons. Firstly, because the material must be capable of withstanding a very high temperature; and secondly, because it must be a conductor of electricity. These two conditions exclude nearly everything except carbon and some of the metals. Of the metals which are sufficiently plentiful, platinum alone possesses the desired qualifications to a degree which renders its use possible. Platinum has a very high melting point, and will stand a very high temperature, but the temperature necessary for an economical incandescent lamp burner is far above that even of the melting point of that metal.

The incandescent electric lamp, though a great advance upon most other artificial sources of illumination, gives us at best only a very inefficient method of obtaining light. That is to say, the proportion of the luminous radiation to the total radiation is very small. When the temperature of a filament is raised by the expenditure in it of more and more energy it becomes increasingly efficient. The efficiency which can be attained is, however, limited by the temperature which the filament will stand. Carbon will stand a temperature higher than the melting point of platinum, and it, therefore, constitutes a more efficient burner.

Certain metallic oxides possess in a remarkable degree the power of resisting very high temperatures. It has, in consequence, been proposed to utilise these in some way, and mention of them has been made in some of the earliest patents for electric lamps. Here, however, the difficulty occurs that metallic oxides are non-conductors of electricity, and, consequently, cannot be used alone. They can only be used in conjunction with some conductor—either a metal or carbon. The Author has tried coating both platinum and carbon with oxides such as alumina, magnesia, lime, &c., but has always met with the difficulty, in the first place, that the coefficient of expansion of the oxide is different from that of the carbon or metal, and, consequently, the coating cracks and falls off.

It has been pointed out by Prof. S. P. Thompson that the temperature of the crater of the arc in an arc lamp is constant, and is the temperature of the volatilisation of carbon. Any other substance contained in the carbons volatilises instantly when reaching the arc. The carbon itself volatilises at that temperature, and all other substances appear to do the same either at that temperature or below. This being the case, it would appear futile to attempt to increase the durability of arc lamp carbons by the addition of any foreign substance.

It is possible, however, that some substance other than carbon may yet be used successfully as the light-emitter in an electric lamp. Even if all metallic oxides are dispersed at a temperature less than that of the arc when used in conjunction with carbon, they are not all necessarily volatilised at that temperature. The volatilisation may be simply a secondary effect, the oxide having been first reduced by the carbon. It does not appear to be impossible that some oxide or mineral substance may be found to be stable at temperatures higher even than that of the arc if there be no carbon present. The great trouble in using any such substance in the same manner as the filament of an ordinary incandescent lamp is that of electrical conductivity. It is possible that some of them might consent to conduct sufficiently if subjected to a very high E.M.F., such as can be produced by transformers. We have seen quite recently slate pencils used in the place of carbons in the arc lamp,

slate being considered an insulator at ordinary electrical pressures. An incandescent lamp, however, with such a filament, if ever constructed, would hardly be suitable for domestic use. Again, although mineral substances when mixed with carbon are all reduced or volatilised in the arc, such mixtures may, nevertheless, be used for incandescent lamp filaments at a temperature much below that of the arc.

Great improvements may yet, however, be looked for in the carbon itself. It is well known that carbon prepared by some processes will last much longer than that prepared by others. The efficiency of a carbon depends upon the temperature at which it can be run. The higher the temperature the greater the efficiency. The limit to the temperature possible is that of the volatilisation of carbon. This temperature in the case of an incandescent lamp is probably lower than that of the arc. The temperature of volatilisation of carbon in vacuo is likely to be much less than at atmospheric pressure. We can, therefore, never hope to get the carbon of an incandescent lamp anything like as bright as the crater of an arc lamp.

Long before the temperature of volatilisation of carbon in vacuo is attained, there is another effect to be considered which puts a far lower limit upon the temperature which can be maintained in practice. Apart from volatilisation properly so called, there is an action going on by which particles of carbon are dissociated from the filament and thrown off upon the glass globe (which is usually called the bulb) of the lamp. This action, unfortunately, begins at a comparatively very low temperature—a little above red heat—and increases very much at higher temperatures, so that, although the filament may be far below the temperature of volatilisation, yet it is fast falling to pieces, and the bulb is becoming greatly obscured by the black deposit of these particles of carbon. It is, then, in overcoming this lower limit to the temperature that improvements must first be made. Some carbons are much better than others in this respect. The best carbon is that which at the highest possible temperature disintegrates at the slowest rate.

Much has been said and written about the so-called efficiency of surface, or emissivity, of different varieties of

carbon. Some varieties have a greater emissivity than others in the proportion of about 3 to 2. That is to say, when running at the same efficiency (watts per candle), two carbons of precisely the same dimensions may be giving different amounts of light by as much as the above ratio. Or two carbons, one having only two-thirds of the surface of the other, may, when at the same efficiency, be giving an equal amount of light. It has sometimes been supposed that the one with the smaller surface is, therefore, better than the other. The reverse, however, is usually the case. The filament with the smallest emissivity is generally the best. A high emissivity usually means a dead black surface, a low emissivity a polished white one. The dull black surface is generally a softer carbon, and one which disintegrates more quickly than the other. The only advantage in the high emissivity is that the filament is, therefore, shorter and may be accommodated in a smaller bulb. The size of the bulb, however, should not be determined by the length of the filament so much as by the candle-power. A large candle-power lamp may have a short filament, but it should not for that reason be put into a small bulb. These matters will be further dealt with in a subsequent chapter.

The chief aim of the lamp-maker, next to that of producing a durable carbon, is to make filaments which will be all alike when finished. To be commercially successful a lamp-maker must be able to make his filaments within a very little all alike in every particular, that is in dimensions (length, circumference, cross-section), in quality of surface, and in specific resistance. Many different methods of preparing carbon have been proposed. Whatever the method, there is one operation which almost all of them necessarily include—that of roasting or baking the material in a furnace out of contact with the atmosphere, in order to drive off, as far as possible, everything contained in the material which is not carbon. In most cases an entire change in the nature of the material is produced by the process. One of the first methods to be tried was that of forming the filament out of a paste made of ground carbon, with a binding agent such as a solution of sugar or caromel. Such a paste was squirted or moulded to the desired shape, dried, and then baked. This, of course,

produced practically the same material as is used for the carbons of arc lamps. The difficulty in this method is to produce fine and uniform filaments. In any event, however, the resulting carbon is not compact enough for the purpose, and it rapidly disintegrates when used in a lamp. Edison proposed a mixture of lamp-black and tar, an utterly worthless process in itself, but one which has, nevertheless, become famous in the history of lamp-making. Processes such as these involve the baking of the material in order to drive off the volatile matter contained in the binding agent.

The successful processes are not those by which the filaments are formed direct from a substance containing carbon as such, but from a material containing carbon in chemical combination, such as silk, hair, woody fibre, or pure cellulose. Such substances require baking at a high temperature in order to reduce them to carbon, their other constituents being driven off by the heat. The process of baking in this case is generally called carbonisation. The only processes which do not include that of baking or carbonisation are those by which the filaments are deposited or built up from the carbon contained in some vapour or liquid such as illuminating gas or petroleum oil.

CHAPTER II.

PREPARATION OF THE FILAMENT.

Some of the methods of preparing filaments will now be described. In spite of all the work that has been done by experimenters during the last ten or fifteen years with a view to providing something new and better, it remains a fact that the original process of Swan's, that of parchmentising cotton thread by sulphuric acid, remains to this day one of the best, if not the best and most easily worked of any. It will, therefore, be described first.

The raw material in Swan's process is pure cotton, such as is sold for knitting, loosely spun into a thread. It is usual, in the first instance, to clean the thread by boiling it in soda or ammonia, in order to take out any grease which may be present in it, and which would prevent the sulphuric acid from acting on those parts which would be thereby protected. It must, however, be thoroughly washed afterwards, in order to remove all traces of the alkali, and be then dried.

It is, after all, an open question if the above process of boiling in alkali does any good, provided that the cotton is as clean as it can be obtained in the first instance, for in spite of the process, there are often found to be places in the thread upon which the acid will not act, or rather upon which it will not act in the time allowed. Sometimes these places are very small, and can only be seen by examining the parchmentised thread very closely, while at other times they will extend for several inches along the thread, and occur at short intervals. No satisfactory explanation of these acid-proof, or partially acid-proof, sections has yet been given, or, at any rate, no satisfactory remedy has been proposed.

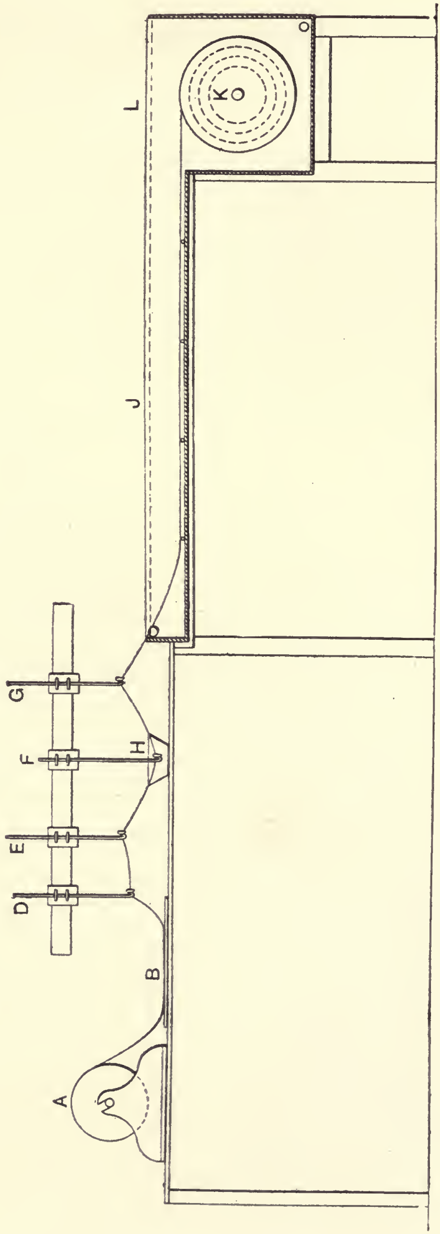


Fig. 1.—Apparatus for Parchmentising Cotton Thread. (Swan's Process.)

When dry, the cotton thread is wound on a drum, and is afterwards unwound and drawn through a dish of sulphuric acid of the required strength, whence it is drawn into water and wound on another drum, which is preferably wholly under the water.

This sounds a very simple and easy process, and is, provided that certain precautions are taken. In the first place, the thread, after passing through the acid, is extremely weak, and must, accordingly, be drawn along as regularly and with as little friction as possible. To insure this, the drum upon which the thread is wound after passing through the acid, and by which it is drawn along, must be driven by power, and must be so geared as to run very steadily and regularly without any jerking. The slightest friction anywhere will put a strain on the thread and will cause it to break.

Fig. 1 shows an arrangement which the Author has found to work very well. At the left-hand end is seen the drum A, upon which the thread is wound in the first instance. K is the drum on which the thread is ultimately wound and which draws it along. The thread has to be guided in its passage from one drum to the other, so as to pass for the right length of time through the acid and then into the water. It must be remembered that the action of the acid continues from the moment when the thread enters the acid until it enters the water, though the thread is only actually under the acid in the dish for a short time, after which it passes through the air until it reaches the water.

In order to guide the thread with the minimum of friction, glass rods with an open loop formed at the end (Fig. 2), may be used, the thread passing through the loop. The advantage of this form is that the thread may be put into the loop while in motion without having to thread the end through first. A number of blocks (D, E, F, G, Fig. 1) are mounted on a bar about 18in. above the bench, each capable of sliding lengthwise along the bar. To each block one of the glass guide-rods is attached, so that it may slide up or down and be held at the required height by a clamp. Between the left-hand drum A and the first guide-rod D, a sheet of glass, B, is laid on the bench. H is a dish containing the acid. J is a

lead-lined trough of some 6ft. in length, terminating in a tank L, which contains the winding drum K, driven from overhead by a band.

In starting the apparatus, sufficient thread is wound off the drum A, so that the end will reach to K. More thread is then wound off A, and laid zig-zag fashion across the glass-plate B. The first length of thread is then dropped into the glass guide-rods and the end is looped on to a projection on the edge of the drum K as it revolves. The thread is, therefore, wound on to K, and drawn along from off the plate B. One of the guide-rods, say F, is now lowered so that it depresses the thread below the surface of the acid in the dish H. On emerging from the acid, the thread passes up through the guide G, and then drops by its own weight into the water in the trough J. The object of the trough J is

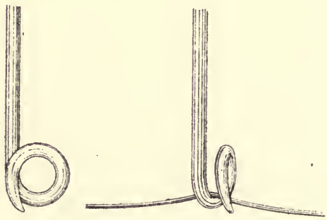


FIG. 2.—Glass Guide Rod for Thread.

that the thread may be examined easily in order to see if it is receiving the proper amount of treatment. It can be best examined while passing along this trough, as it is readily seen in the water against the lead lining of the trough. On coming out of the acid dish, the thread has a transparent and bright appearance, like a string of jelly. When it enters the water it is immediately changed from the transparent to a semi-opaque condition. It is at this point, after entering the water, that it must be constantly watched to see if it is receiving the proper amount of treatment. If it is not being done sufficiently, it will have a core of unconverted cotton running through it continuously or in patches. If it is receiving the proper amount of treatment it will appear as a semi-opaque homogeneous thread. On the other hand, if

the treatment is too long the thread will probably break. It is, therefore, necessary at starting to give it less than the proper amount of treatment. The acid dish can then be moved gradually further back, so that the thread has a longer distance to travel from the acid to the water. If more treatment than can be given by this means is required, the speed of the drum K must be reduced. When the apparatus is adjusted, the acid dish, the edge of which is ground level, is covered by pieces of sheet-glass so that the acid is not exposed to the air, only a small opening being left just where the thread enters and leaves. As the thread is drawn along, it is, of course, taken up off the glass plate, and the attendant must take care to have more thread wound off the drum and laid across the glass plate before the last lot is used up, or a breakage will occur. Another plan is to drive the drum A as well as K by power. The thread is then unwound from A as it is wanted. The former method, however, gives less trouble. By the method of laying out the thread in zigzag rows on the glass plate the attendant has sufficient time to examine the thread as it passes along the trough and to keep the apparatus working properly. A sheet of glass is required, because the fine fibres of the loosely-spun thread are apt to catch if laid out on an ordinary wooden bench, unless it is of hard polished wood. The slight momentary strain produced in this way is often sufficient to cause a breakage. In order to still further reduce the strain, porcelain or glass pulleys driven at the proper speed may be used instead of the glass guide-rods (Fig. 2). The latter, however, are much simpler, and answer the purpose quite well. One girl can easily work the apparatus. There is a supply of water at the bottom of the tank L, with an overflow at the end of the trough J. Fresh water is thus always coming in by the drum, and passing along the trough. The strong acid carried into the water by the thread is in this way washed out without getting far along the trough.

The strength of the acid is an important consideration. A specific gravity of 1·64, as recommended by Mr. Swinburne, works very well. This is a little stronger than that mentioned by Mr. Swan in his patent. The temperature at which it is used should be from 60° to 70°F. A large quantity of acid

should be made up to the required strength and drawn off in small quantities as required.

It is a curious fact that the finer threads are more easily worked than the larger, and are less liable to breakage. A much shorter immersion in the acid is required, as a rule, for the larger sizes of thread than the smaller. The speed at which the thread must travel is from 12ft. to 24ft. per minute, and the length of thread under acid (from where it enters the acid to where it enters the water) will be from 12in. to 36in. The actual time, therefore, during which the acid is acting on the thread will be from two and a-half to fifteen seconds, according to the quality and size of the thread and the tightness to which it is spun.

Guide-rods may be arranged in front of the winding-drum K, so as to gradually move the thread along the length of the drum and ensure it winding evenly. This, again, is an unnecessary refinement. A glass rod fixed to a piece of wood, which can be laid across the trough and moved by hand every now and again, is quite sufficient. It does not matter if the thread is wound on the drum in several layers, as it is easily wound off afterwards, and the washing of several layers does not take much longer than a single one. If only one layer is wound on the drum, the number of drums and washing tanks is multiplied, and time is lost in changing the drums more frequently. The drum K may be made with a wood spindle and ends, and covered with copper gauze, which allows of a more rapid and thorough washing of the thread than a solid surface would do. When a drum is filled it is lifted out of the tank L and removed to another tank, in which the thread is further washed by a continual circulation of water. In twelve hours or so all traces of acid will have been removed from the thread, which is then ready for drying.

The parchmentised thread quickly dries on exposure to dry air, and in doing so it hardens and contracts. Consequently, in order that it may dry evenly and straight, it is necessary to take it off the drums on which it has been washed and hang it up. A convenient method of drying is shown in the accompanying sketch, Fig. 3.

A number of bars of wood are fixed parallel to each other, 8ft. or 9ft. above the floor of the drying-room and about

2ft. apart. On each side of these bars, B, are secured a number of porcelain insulators, A A, at intervals of a little less than their own diameter, about 2in. Immediately below the bars is fixed on the floor a framework consisting of three boards set up edgewise, the two outer ones not reaching to the floor by 2in. or so, except at the ends, the space between the two outer boards and the centre one being a little more than the width of the insulators. In order to dry the parchmentised thread, the drum on which it is wound is taken out of the washing tank and set in a stand so that it

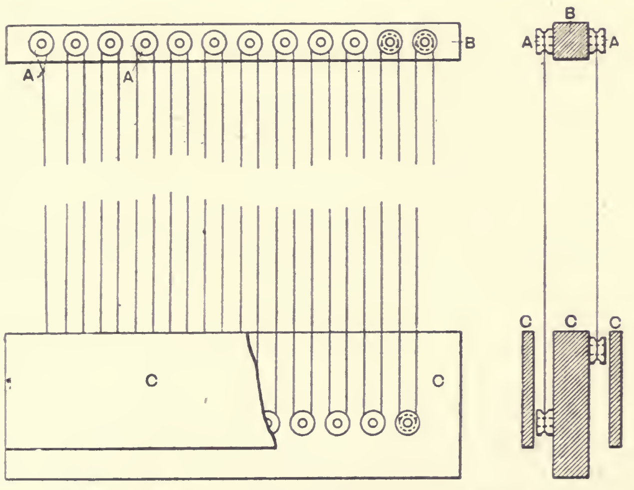


Fig. 3.—Method of Drying Parchmentised Thread.

can be turned round. One operative takes the end of the thread and ties a loop on it, and standing on a pair of steps, hangs the loop on the farthest insulator. A second girl unwinds the drum, and a third one takes the thread as it comes off and hands it to the first one, who hangs it again over the second insulator, while she (No. 2) proceeds to hang another insulator in the loop thus formed and lower it between the boards, the length of the loop being so adjusted that the insulator hangs at the bottom of the outside board. This operation is continued until the whole length of the parchmentised thread is hung up, with a weight on every loop to

keep it stretched. As the thread dries it contracts and raises the weights hanging in the loops to nearly the top of the boards. When dry the thread has become again more transparent and has somewhat the appearance of catgut. It is then taken down and wound on a reel, and is ready for the next process of cutting to size. The boards, C C C, are for the purpose of preventing the weights from falling off the thread and the loop from twisting on itself. When taking the thread down the weights are easily shaken off. The outside boards, C C, are fixed above the ground so that the weights can be got out easily if they fall between the boards. This method of drying insures that the thread all along gets the same tension. For thick thread it may be necessary to use heavier weights than for the smaller sizes.

Another method is to have porcelain pulleys instead of the insulators, and the bottom ones fixed as well as the top. The thread is then wound up and down, and one weight only hung upon the end. This method, however, puts on a varying strain owing to the friction in the pulleys, and some lengths will be pulled tighter than the others. Besides, the thread, as soon as it begins to get dry, stiffens, and will not readily pass over the pulleys. In the first method it will be seen that the thread is not required to move past the pulleys as it contracts.

The chemical action of this parchmentising process is remarkable, inasmuch as the parchmentised thread appears to retain the same composition as the thread ($C_6H_{10}O_5$) from which it is made, though in appearance it is an absolutely different substance. There is, however, an increase in weight equal to about 8 per cent. The substance so produced is called amyloid, and, as will presently be explained, it can be produced by other methods. The amyloid thread produced as shown has a rough and uneven surface, and it must be shaved down and made even before it is fit for use. This cutting down is accomplished by pulling the parchmentised thread through sharp-edged draw-plates. As there are often lumps on the thread, it has to be drawn through several sizes of draw-plates in order to remove these lumps before it is passed through the smaller sizes, which will shave it along its whole length. If it is drawn through too small a plate at first it

will break when the thick parts reach the draw-plate. Steel draw-plates can be used, but the cutting edge will very soon become blunt. Jewelled plates are therefore generally used, and even the hard stones used in these frequently require sharpening. The size of thread parchmentised is proportioned as nearly as possible to the size necessary for the particular filaments required, so that there shall be no more cutting down than is necessary for obtaining even filaments.

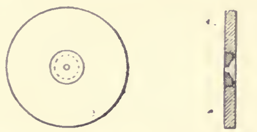


FIG. 4.—Circular Jewelled Draw-Plate for Cutting Parchmentised Thread.

The draw-plates used for the larger sizes of thread may be similar to the ordinary jewelled wire draw-plates, but with a sharp-cutting edge (Fig. 4). For the smaller sizes, however, below about twenty mils, it is necessary to use split draw-plates, owing to the difficulty of threading them.

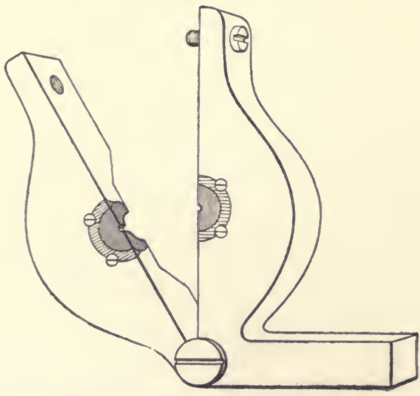


FIG. 5.—Split Jewelled Draw-Plate for Cutting Parchmentised Thread.

Fig. 5 is an illustration of a split draw-plate. The ends of the larger sizes of thread can be easily pointed with a knife, be pushed through the circular draw-plates, and be pulled through at first with tweezers. It is, however, very difficult

to do this with the smaller sizes, and it is, therefore, better to use the split form. The circular form is used whenever possible, as it costs very much less than the split one. The thread must be drawn through the plates as regularly as possible, and for this reason the plate is fixed upright on a bench, and 12in. or so behind it there is a wooden drum turned by power. A couple of feet or so of the thread is pulled through the die by hand and then turned once or twice round the drum, which then does all the pulling in a steady and even manner, so that the thread is much less likely to break than if it is drawn by hand. A guide should be fixed both in front and behind the draw-plate, and in line with the hole, so that the thread is always drawn through perfectly at right angles to the front surface which contains the cutting edge. If the thread is not drawn through straight it will be cut unevenly and of an oval section instead of circular. When the jewel becomes dull, and will no longer cut properly, it can be sharpened and made as good as new again, though it will by the process be made larger in the hole, and will only serve for a larger size of thread than before. The thread must be passed through several sizes of plate, each a little smaller than the last. The amount cut off by each plate should not be more than about 5 per cent. of the diameter of the thread, except, perhaps, at starting, when lumps only are being cut down. This process of cutting down when properly carried out gives the thread a smooth, polished surface, and makes it perfectly circular. It is then ready for being blocked for carbonisation.

There is another process of treating cotton so as to produce a substance practically identical with Swan's parchmentised cotton thread, which possesses several great advantages over that process. It consists in dissolving cotton wool in a solution of chloride of zinc. The viscous solution produced by this means is squirted through a small hole into a vessel containing alcohol which causes it to set and harden. The great advantage of this method is that it produces a thread of amyloid of uniform diameter throughout, and which can be made of any size, according to the size of the hole through which it is squirted, and which requires no after process of cutting down by means of draw-plates. This is a very great advantage

as the wear and tear of the draw-plates is considerable and the cost of the process is saved. This process, like all others, requires great care if uniform results are to be achieved. The strength of the zinc chloride solution and the amount of cotton dissolved in it must be carefully regulated, as also must the temperature at which it is kept while the cotton is dissolving. There are several difficulties met with. The cotton wool when put into the solution carries down with it a quantity of air, which, as the cotton dissolves, is seen in the form of bubbles all through the solution. The solution produced is of such a viscous nature that if left to itself these bubbles will remain wherever they happen to be, or at any rate they will rise so slowly that it would be a matter of weeks for them to reach the surface. In order to get rid of them the solution is filtered and at the same time heated under a vacuum. In this way most of them may be extracted. If they are not got rid of before the solution is squirted, the very small ones will remain in the squirted thread, while those which are of a size equal to, or larger than, the diameter of the nozzle of the squirt, will cause a break in the thread. The smallest air bubbles are the most troublesome, as their presence may not be detected until the filament comes to be lighted up, when a bright spot will appear at the place where the bubble was located. It is also very important that there should be no lumps, or parts of the solution thicker than the rest. When these occur, and arrive at the nozzle of the squirt, they may retard or stop the flow, and greater pressure has to be put upon the solution to force it through. As soon as the lump is through, the thinner portion of the solution following it will run too quickly. The result is that the thread is not uniform in diameter. Constant stirring during the dissolving will prevent the formation of lumps to a great extent. Messrs. Wynne and Powell, who patented this process in 1884, give the specific gravity of the zinc solution required as 1·8 and the temperature 100°C. The material finally requires thorough washing in alcohol or water. The drying may be done in the same way as already described for Swan's process.

Cotton is again the raw material of another process for making filaments — the process invented by Mr. Weston. Cotton is converted by the well-known process into pyroxyline,

and then into the material known as celluloid. This is rolled into thin sheets, which are then treated with ammonium sulphide, which reduces them again to the chemical state of cellulose, though leaving them transparent and flexible. The sheets are then treated with bisulphide of carbon or turpentine, in order to remove all traces of sulphur, and are afterwards either cut up into narrow strips or pieces are punched out of them of the required size and shape. The strips may be made into spirals or other forms by winding them on mandrils and heating them to a temperature which will stiffen them, so that they will retain their shape when removed from the mandrils. The sheets of celluloid may be cut into strips, or punched out, and the ammonium sulphide treatment applied afterwards. Carbons made by this process have a lustrous, highly-polished, metallic appearance.

A process producing very similar filaments to the above is that which uses a peculiar liquid hydrocarbon called furfurol as a basis. This liquid is treated with sulphuric acid, and the black liquor produced is poured upon a sheet of glass. A second sheet of glass is then placed upon the top. The space between the sheets is determined by a strip of paper placed along the margin. In about twelve hours the liquor will have set, and the glass plates are forced apart. The sheet of black material produced adheres to one of the glass plates, from which, however, it can be easily detached under water. The sheet is then cut up into strips, which can be moulded to shape in the same way as in the Weston process, by heating, and are then ready for carbonising. This process, again, may be considered as starting from cotton, as the liquid furfurol is obtained by the distillation of cotton or other form of cellulose. The Author has, however, no personal experience in working this process.

Cotton was, again, the basis in a process proposed by Prof. Crookes. Cotton was dissolved in a solution of cuprammonia, and sheets of the substance were formed on glass, as in the last process. The Crookes' process has, however, not been extensively used. The Author has tried squirting filaments of this preparation, but owing to the very great shrinkage of the squirted thread when drying, the method was found to be useless.

Parchmentised paper was proposed by Swan before his cotton process. Ordinary hard paper, without any chemical treatment, has also been used. In all of the above processes the carbons are produced by the carbonisation of cellulose or some modification of it. All vegetable fibres contain cellulose, cotton being nearly pure cellulose, and many of them can be carbonised and made to serve for lamp filaments either with or without any chemical treatment. Bass fibre, tampico fibre, and many kinds of grasses have been tried. Some of them make very good lamps, but the great objection to all is the want of uniformity in size and composition. It is not likely that any of them will survive as commercial lamp filaments for this reason. Edison, as is well known, used bamboo, and with the aid of very ingenious machinery stamped out pieces of the required size. Specimens of the bamboo in the various stages of reducing to size were exhibited at the Crystal Palace Exhibition in 1882, and will be found described and illustrated in Dredge's "Electric Illumination."

Many other substances have been tried. Of animal substances silk is undoubtedly the most successful, and may be carbonised without any previous chemical treatment. All animal substances, however, require special precautions in the matter of temperature during carbonisation.

CHAPTER III.

CARBONISATION.

The process of carbonisation consists in baking the carbonisable material at a very high temperature out of contact with the air. During the process the material will shrink and become hard and stiff, and will take permanently whatever shape it happens to be in at the time. Special arrangements have, therefore, to be made to control the shape of the filaments. The methods adopted for accomplishing this will now be described.

First of all in the case of long threads as produced by Swan's process.

For making plain horse-shoe filaments the thread is wound on carbon blocks or forms. Arrangements must, however, be made for the shrinkage. The material will shrink both in length and thickness, becoming about one-third smaller. If wound on a solid carbon block and then carbonised the thread will be broken in every turn or loop. Various methods of allowing for the shrinkage have been used. The one shown in the illustration (Fig. 6) is a good one.

A is the carbon block, with two holes about a quarter of an inch diameter drilled in it. B is a circular piece of carbon, the diameter of which is the same as the thickness of the block A. There are two holes drilled into B corresponding to those in A. At the top A should be well and smoothly rounded. A and B are connected together by sticks of hard wood C C, which may fit tightly in the holes into which they are driven home, reaching, therefore, to within half an inch or so of the top of the block. The thread is then wound round the block and end piece. It may either be wound on by hand,

or the block may be clamped in a machine which will turn it round and wind it evenly, the machine feeding the block forward at the same time. When the block is filled it should be wrapped up in thin calico or paper, and it is then ready for packing in the crucible. By using the wooden sticks C C instead of a solid carbon block, the shrinkage of the thread is allowed for. The block is placed in the crucible with A uppermost, care being taken that it stands loosely and is not

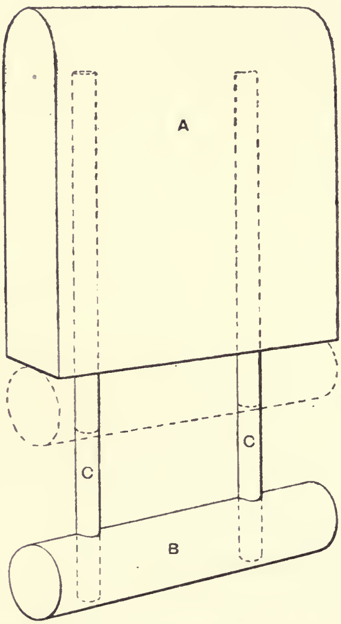


FIG. 6.—Carbon Frame for Carbonisation of Single-Looped Filaments.

packed too tightly. As the process of carbonisation proceeds, the wood C C shrinks, and the block A descends at the same time that the thread contracts. By carefully regulating the temperature the thread is thus allowed to contract without being strained sufficiently to break it, but just enough to keep it perfectly straight. The length of the sticks C C is such that when the carbonisation is complete the block A will have sunk upon the end-piece B, the sticks being entirely enclosed in the holes. The illustration shows the block A and the

end-piece B in position for winding on the thread. After carbonisation A and B are close together.

If it is desired to get a long filament into a comparatively short bulb, the filament may be bent round into a loop, as in the Swan lamp. This may be accomplished by simply using two of the round end pieces of the carbon blocks already described, joined together by the wooden sticks. The thread is then wound with a complete turn round the carbon at each end, the wooden sticks being long enough to allow of two filaments end to end. Instead of winding the thread straight down from one carbon to the other like the figure 0, it may be crossed like an 8. The use of solid carbon, however, is not good, owing to insufficient allowance for contraction in the

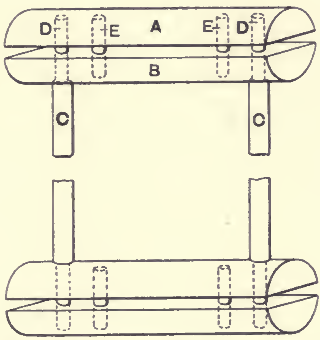


FIG. 7.—Carbon Frame for Carbonisation of Double-Looped Filaments.

loop. The thread will draw round the carbon in some degree as it shrinks, but only to a small extent, the result being that the filament is strained in the loop. This may be overcome by using split carbons instead of solid ones to wind the loop upon, as in Fig. 7.

A and B are the semi-circular carbons. C C the wooden sticks, which are smaller (D D) where they pass through the holes in the carbons. Each piece A B has two other holes E E, into which are inserted short wooden sticks. In this way allowance is made for the shrinkage in the loop of the filaments as well as in the long sides.

In every process of lamp manufacture it is necessary to use the utmost care to prevent waste. Very slight differences in

the ways of carrying out some of the processes may make all the difference in the result. Carbonisation is one such process. If the filaments are properly packed and handled, and the heat of the furnace is properly regulated, filaments made in the above manner may be obtained almost without loss, certainly with a breakage of not more than 2 or 3 per cent.

It is not sufficient, when the thread is wound on blocks in the way above described, to pack the blocks, whether wrapped up or not in calico or paper, into a crucible and fill up all the remaining space with powdered carbon. The carbon powder will prevent the top part of the block from sinking during the shrinkage, and the result will be the breaking of most of the filaments. The blocks must be perfectly free to move as the shrinkage proceeds. The best way to insure this result is to use a carbon box inside the crucible. The box should be half an inch or so deeper inside than the length of the blocks when wound. A box should accommodate about ten blocks. The blocks are put in with the part A uppermost. Between each block is a thin plate of carbon about one-eighth of an inch thick. These plates slide easily in grooves in the sides of the box. By this means each block is in a separate chamber, and is entirely free to move during the shrinkage. A carbon lid fits loosely on the top of the box. The whole carbon box is then put into a "plumbago" crucible of the same shape, but having a clearance of half an inch or so all round, and an inch higher than the lid of the box. The space between the box and the crucible is then filled up with powdered charcoal to the level of the top of the crucible, and the crucible lid is then put on and plastered down with fire-clay, care being taken to leave one or two small gaps in the fire-clay for the escape of the gases. If this is not done, the fire-clay may hold the lid so tightly that the gases cannot escape until a great pressure has been produced in the crucible, when the lid may be thrown violently off and the contents spoiled. No powdered charcoal is required in the carbon box, and the filaments cannot be burnt at all by the small quantity of air left in the box. Before the temperature of red heat which would be required to burn the filaments is reached, most of the enclosed air has been driven out of the crucible by expansion. The gases produced by the charring of the filaments, the wood sticks and

the calico wrapping have been coming off in such volume as to sweep out practically all the remaining air, so that by the time the filaments are hot enough to burn there is no air left in the box to burn them.

Flat filaments, and those which are shaped before carbonisation, of course, require a different method of packing in the crucibles. Spirals and such like forms must be packed in carbon powder or plumbago as loosely as possible, so that they may retain their shape during the shrinkage. Such a method, however, is very costly, owing to the comparatively small number of filaments which can be accommodated in the crucible. Flat filaments may be packed between layers of paper or calico with a carbon block for a weight on the top. If calico is used, it should be partially charred before using, as it shrinks during carbonisation more then most filament substances.

Filaments of different material require different treatment during carbonisation. Some materials will allow of being heated much more rapidly than others, and some require a greater and more prolonged heat than others. Generally speaking, however, it may be said that the temperature should be raised very gradually and evenly, and should be raised as high as possible.

The construction of the furnace is also an important consideration. The fire must be in a separate chamber from the crucibles, which must not be liable to be knocked about when the fire is being stoked. It is well if the fire can be made to reach the crucibles evenly all round. This, however, is not important, provided that the temperature is at no time suddenly raised.

The illustration, Fig. 8, shows a form of furnace which works very well. The fire is in a chamber on the left. The hot gases pass over the "bridge," over and between the crucibles, and down through a flue into the chimney shaft.

A is the fire, B is a "bridge" of fire bricks, C is the floor of the chamber, D is the flue leading to the chimney shaft, E E are the crucibles, F is a damper in the flue D. The furnace door is made of fire-clay, and is bound together with iron. It can be raised and lowered by means of a chain and counterweight running over a pulley. The fire door can also be

arranged in the same way. The furnace door has a small peep-hole in the centre, into which is fitted a fire-clay stopper. This hole also serves for the insertion of the pyrometer G, which is required during the first part of the process. The furnace must be substantially built with the best fire-clay bricks, and must be held together by iron tie rods and bands. The crucibles must be of the plumbago type, and of the best quality. The

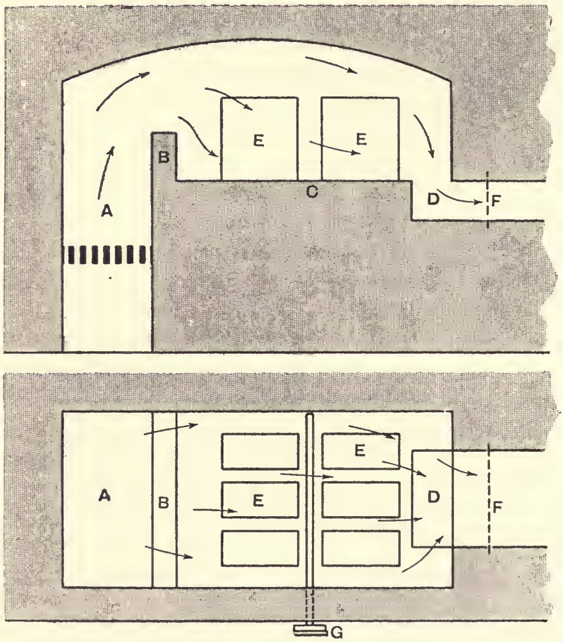


Fig. 8.—Carbonising Furnace.

temperature they have to withstand is so great that they will only survive a few bakings.

The part of the process of carbonising which requires most attention is the first, that is to say, before the temperature of red heat is reached. If a crucible containing filaments wound on blocks and packed as described is put at once into a hot furnace, or if the temperature is raised too suddenly, the result will probably be that all the filaments are broken. If quickly

heated, the filaments on the blocks begin to contract before the wooden sticks, which take a longer time heating, owing to their greater thickness and the quantity of gases which they give off. These gases, being very rich in hydrocarbons (being, of course, the ordinary products of destructive distillation of wood), deposit a thick coating of mess on the filaments and on the carbon block. As the temperature rises this mess is further decomposed, leaving behind a residue of carbon, which firmly cements the filaments together and to the carbon block, thus spoiling them all. When, however, the temperature is slowly and gradually raised, the contraction of the filaments and the sticks takes place at the same time, and the gases which are given off from the sticks pass out without leaving any deposit whatever. Gases from the wood continue to be given off up to red heat, as may be seen by a flame at the small holes left in the luting of the crucible lid. The parchmentised thread

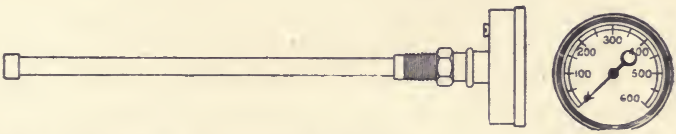


FIG. 9.—Pyrometer for Indicating Temperature during Early Stages of Carbonisation.

itself, having the composition $C_6H_{10}O_5$, is supposed to give off only steam or its equivalent.

It will thus be readily understood that some kind of pyrometer must be used, during at any rate the first part of the heating, up to nearly red heat. Fig. 9 gives an illustration of a suitable instrument, which is graduated up to 600°C., or to just dull red heat. The instrument works by indicating on the dial the difference in expansion of rods or tubes of different metals contained within the outer tube, and is sufficiently good for the purpose, actual temperatures not being so important as the rate of rise of temperature. The tube of the instrument is inserted through the hole in the furnace door, a support on the back wall of the furnace being fixed in the right position for the end to rest upon. The position of of the tube may be just above the crucibles, or between two rows of them.

The crucibles being placed in position in the furnace, the door is lowered into its position, and cemented round the edge with fire-clay. The pyrometer is then inserted through the hole and is also cemented round where it passes through the door. The fire is then lighted, and by means of the damper is kept very low at first; eight hours at least should be allowed for traversing the range of temperature covered by the pyrometer. The first six or seven hours of this time may be in daylight, but by the time that the highest reading on the pyrometer is reached it should be dark, as the regulation from this point will have to be done by aid of the eye. The eye is, of course, much better able to judge of colour (temperature) after dark than in daylight, when, indeed, the first dull red heat could not be distinguished at all. The highest temperature indicated by the pyrometer having been reached, the instrument is withdrawn and the peep-hole stopped with the fire-clay plug. It will be necessary from this time to watch the temperature through this hole, the plug being withdrawn from time to time for the purpose. Another five or six hours should be occupied in bringing the temperature gradually up to a bright red heat, and when this is reached the full power of the furnace may be applied, and three or four hours more will be occupied in bringing the temperature up to a white heat. The temperature which can be attained by a furnace of this kind is so great that the best fire-bricks will begin to run, and, having raised the temperature to the highest point, there is probably not much advantage gained in maintaining it for any length of time. The fire may, therefore, be allowed to die out and the furnace to cool down. This again must be done gradually, not on account of the danger to the filaments, but to the furnace. The furnace-door and the fire-door must be kept closed. Rapid cooling will have a very deleterious effect on the furnace, which will require re-building much sooner than it otherwise would do. Twelve hours at least should be allowed for cooling. The crucibles should not be disturbed until they are cool enough to be taken hold of by the hand. If they are handled while too hot, they are likely to be bumped about, and the filaments will be damaged. The wear and tear on a furnace which is used in this way, alternately heated and cooled, is much greater than

that on a furnace, such as a glass furnace, which is kept constantly going at one temperature. If heated and cooled off every two days, it will require re-building probably every six months. When the crucibles are cool they are withdrawn and placed on a truck and wheeled to the room where they are to be unpacked.

With a furnace of this kind, where the fire is all on one side of the crucibles, it might be expected that there would be trouble owing to uneven heating. There is, however, no trouble when the temperature is raised slowly, as it should be. The powdered charcoal used as packing and the carbon box are comparatively good conductors of heat, and consequently help to distribute the heat evenly within the crucible. On no account, however, should lamp black or carbon of that nature be used for packing, as it conducts heat badly, and will take a very long time to cool down afterwards.

Various forms of pyrometers have been proposed for temperatures above that for which the one described is suitable. These usually depend on the increase in the electrical resistance of a platinum wire with the temperature, and of course involve an ohmmeter or some other electrical measuring apparatus. Such a pyrometer might be useful in certain cases, but for ordinary work it is not really needed. Good soft coal should be used in a furnace of the kind described, as the temperature is more easily regulated than with hard coal requiring a stronger draught, and the highest temperature is more easily obtained.

Petroleum oil has been proposed as the fuel for carbonising furnaces, but the Author is not aware that it is used in any factory. Petroleum or gas furnaces might be designed to give very regular and even heating, but would probably not be good for high temperatures. A very high temperature can, of course, be obtained by using ordinary coal gas with an air blast, but it is an expensive and troublesome method, and it is also very difficult to obtain an even heating. One part of the crucible may be nearly melting while another is comparatively cold.

As the temperature at which a filament is run after it is in the lamp, and also during the process of manufacture subsequent to carbonisation, is greater than that which can be

obtained in the furnace, it might be supposed that there would be no need to carbonise at a higher temperature than a red heat, sufficiently high only to make the filaments conductors of electricity, the carbonisation being completed by the subsequent heating with the electric current. This, of course, would give a considerable saving in the cost of the furnace repairs and renewals of the crucibles. Although such a method might perhaps answer in certain cases, it will, however, generally be found that the higher the temperature attained in the furnace the better will be the filaments, and also the more uniform will be the results. The specific resistance of filaments baked at a red heat is much greater than those which have been raised to a white heat. Filaments of different bakings, which have all been brought to a bright white heat will be more nearly alike in specific resistance than those baked only at a bright red heat. In the latter case, not only are the filaments of separate bakings liable to differ from each other, but the filaments from the same crucible may be found to vary in specific resistance. The subsequent heating by the electric current will cause the specific resistance to fall. It will do so even with the filaments which have been carbonised at the highest possible temperature in the furnace. But even then, after the application of the current, those carbonised at the highest furnace temperature can be the more easily brought to uniformity. Especially is this the case if the filaments are to be flashed. If the filaments are uneven before flashing, they are much more likely to be uneven after flashing than if they started uniform and of a definite specific resistance, even though that specific resistance be not the final one.

Having got the crucibles safely from the furnace to the bench where they are to be unpacked, the first thing to be done is to remove the lids. This can usually be accomplished without difficulty, though it is sometimes necessary to use a good deal of force, owing to the lid having become fused in places to the crucible. Care must be taken that the crucible is not knocked or jolted about. The lid being off, it will first be noticed that the powdered carbon has sunk considerably, the space between the carbon box and the crucible being no longer full as it was when the lid was put on. This subsidence is due to the air

which was originally imprisoned by the carbon having been driven out, and not to any loss of the carbon by burning or otherwise. If through insufficient luting of the lid some of the carbon powder has been burnt, it will be at once apparent by a brown or yellow powder upon the top, which is the ash always left by the wood charcoal such as is used. No ash, however, is usually seen, and no carbon dust has been burnt.

It must be borne in mind that the filaments now in the crucibles are very different things from what they were when put in. They are now very brittle and easily broken. Consider for a moment the condition in which they now are, and it will be readily understood that the greatest care must be used in handling them. The parchmentised thread and the wooden sticks between the two parts of the carbon block are now carbonised and have shrunk, so that the top or larger piece of the block has sunk down upon the lower part. The parchmentised thread, now carbon, is still in one length wound round and round the carbon block. It is, therefore, evident that it will not do to lift out the block in the reverse manner to that by which it was put in. If this is done, the top or larger block being lifted out, the filaments will probably not have the strength to raise the lower one, which will remain at the bottom of the box, having broken through all the filaments. This would not matter if they were all to break at the lower end. It is, unfortunately, an invariable rule with filaments to break at a point which will render them useless. The sliding carbon partitions, however, provide an easy method of safely withdrawing the blocks. The carbon box is lifted out of the crucible, and is gently turned on its end, the lid having been first removed. Each block of filaments now rests on one of the thin carbon plates. These are, then, carefully withdrawn one by one with the blocks of filaments lying flat upon them.

The next thing to be done is to get the filaments off the blocks. Great care must be taken in handling the blocks at this stage, because the two parts are only held together by the filaments themselves, the wooden sticks, which originally fitted tightly into the carbon blocks, having shrunk during the carbonisation so as to become quite loose in the holes, and no longer serve to hold the two parts together. If the

blocks were wrapped in paper or calico, the now carbonised wrapping must be undone. This is easily accomplished by cutting it along the edge of the block with a knife, when it can be turned back and the filaments exposed to view. With a pair of scissors the upper side of all the filaments may now be cut across between the two parts of the carbon block. Then with a knife the lower side of the filaments may be cut downwards against the carbon plate upon which they are lying. The round end piece of the block can, therefore, be removed with the tail ends of the filaments. The large part of the block can now be lifted up with all the filaments hanging upon it. They should be perfectly straight, and if they have been skilfully handled there will often be not so much as a single breakage.

They may now be tipped off the block into a suitable tray or box and put away until wanted. They must, however, be kept in a perfectly dry place or air-tight box if they are to be kept for any length of time, as they may absorb moisture, with the result that, when they come to be heated by a current of electricity, they may break, or pieces may chip off, owing to the sudden generation of minute quantities of steam. If filaments are allowed to get into this state, the moisture may be removed safely by slowly baking them at a temperature less than red heat.

Looped filaments are taken off the blocks in a similar way. The filaments are cut midway between the loops and are then gently pulled off the carbon blocks. There is no difficulty in unpacking flat filaments carbonised between paper or calico. Spiral and other forms carbonised loose in powdered charcoal are more difficult to withdraw without breakage.

CHAPTER IV.

MOUNTING.

The process of joining the carbon filament to the leading-in wires (the wires which support the filament and convey the current of electricity through the glass) is usually called "Mounting." It may be carried out in a variety of ways, some of which will now be described.

Platinum wire is always used to carry the current of electricity through the glass bulb to the filament. Platinum is employed because it has a coefficient of expansion nearly the same as that of the glass which is used, and because it will stand the necessary heating in the blowpipe flame without melting or oxydising during the process of "sealing-in." Other metals having a different coefficient of expansion will not do, as the glass will crack at the seal. Various means have been tried to obviate the use of platinum, on account of expense. Several experimenters have claimed to have produced alloys of other metals which may be used as a substitute for platinum. Alloys having about the same coefficient of expansion as glass can undoubtedly be produced, but they are open to the objection that they are unable to stand the temperature of melting glass or the action of the blowpipe flame without melting or burning, so that, even if the glass does not crack, there is likely to be a leak from the imperfect fusing of the glass to the wire. In order to make a safe seal it is, consequently, necessary to make a very long one, and extra time and trouble are required. No such method is likely to supersede platinum, as the supply of this metal appears to increase with the demand. The high price to which it rose a few years ago was not maintained, and it seems probable it will continue

to fall. It takes only a small amount of extra labour and a few failures to cost as much as the very small amount of platinum which is really necessary. If a cheap alloy could be produced, which could be used in exactly the same way as platinum is now used, it would, no doubt, very soon take the place of that metal altogether, but it is a question if any substitute requiring a more elaborate seal will be able to do so. The platinum need only enter the lamp for a short distance. If it is desired that the filament be placed some distance away from the seal, copper wires may be fused to the platinum and the filament joined to the copper. Thin copper and platinum wires can be easily fused together. The ends of the wires are held in a small pointed blowpipe flame. The copper quickly melts and a small bead is formed. While this bead is liquid the hot end of the platinum wire is stuck into it and both are removed from the flame when it is found that they are firmly united. If the wire within the bulb is required to be of some length, it will be necessary that it be supported, or the weight of the filament may cause it to bend over. It is easy to stiffen the wires by the aid of glass. A coating of glass may be fused on the wires, or a T piece of glass may be used, so that the ends of the cross-piece support the wires, the tail of the T being fused to the bottom of the bulb.

The joint between the leading-in wires and the filament may be a simple mechanical one, the filament being clamped in some way to the wires. A socket can be formed on the ends of the wires and the filament inserted and the socket squeezed tightly upon the filament. If the filament be flat it may be held to the flattened ends of the wires by a small bolt and nut. A split holder, with a ring on it exactly like a small crayon-holder, such as is used by artists, may be used. In each of these methods the filament is held simply by mechanical pressure.

All these methods, which were used in the early days of lamp-making, have, however, been abandoned as unsatisfactory or too costly. The filaments were apt to work loose, owing to expansion and contraction with temperature. In the earlier forms of the Lane-Fox lamp a hollow carbon tube was used, into which the platinum wire was inserted at one end and the filament at the other, with some kind of carbon paste to make the joint firm. Fig. 10 shows an early form of

Swan lamp with the crayon-holder joint; Fig. 11 shows a Lane-Fox lamp; and Fig. 12 shows a Maxim-Weston lamp, with platinum bolt and nut.

Edison for a long time made a socket joint, which was electro-plated with copper, the deposit of copper extending

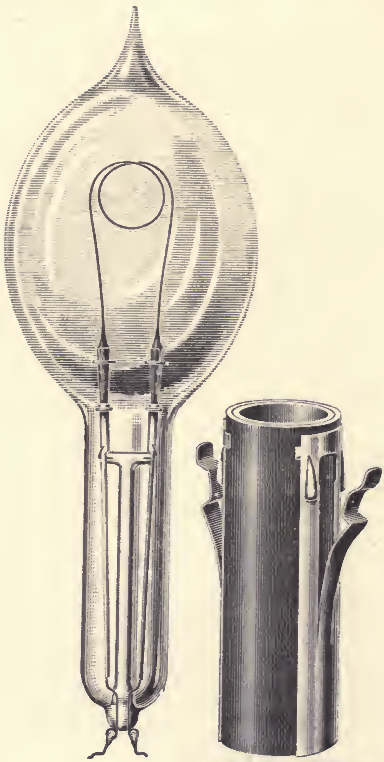


FIG. 10.—Early Swan Lamp, showing Crayon-holder Joint.

a short distance along both the wire and the filament. This made a good joint, both electrically and mechanically, but it was abandoned some years ago in favour of a simpler form. The most common form of joint is a simple socket with a deposit of carbon at the junction, in place of the copper deposit used by Edison. A simpler form is that made by a deposit of

carbon without any tube or socket. The most simple form of all, however, is where the joint is formed by a small lump of carbon paste. This was used by Edison after the electroplated joint had been given up. The deposited carbon joint is the most satisfactory as a joint, and is consequently the most widely adopted, though it is more troublesome and

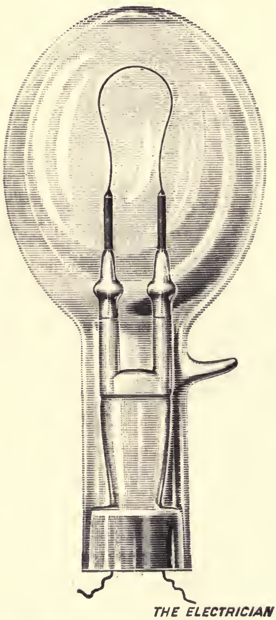


FIG. 11.—Early Lane-Fox Lamp, showing Carbon Tube Joint.

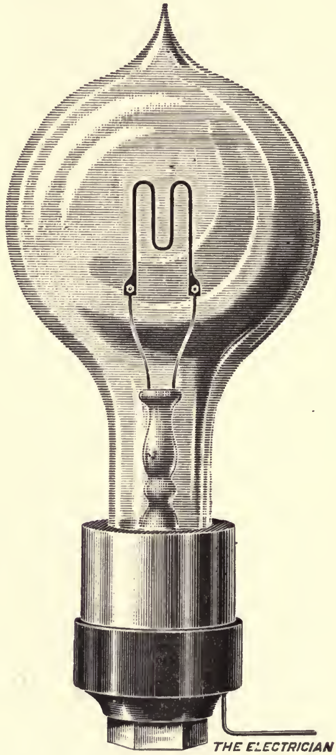


FIG. 12.—Early Maxim-Weston Lamp, showing Bolt and Nut Joint.

expensive to make than the paste joint. The deposited joint is made by heating the junction of the filament and wires by electric current in an atmosphere of hydrocarbon gas, or under a hydrocarbon liquid. The gas is seldom used, as it is too slow. The liquid gives a much more rapid deposit, but has the disadvantage of getting more or less all over the

carbon and wires, and must consequently be driven off again before the filament is sealed into the bulb.

The first thing to be done towards making the joint is to prepare the platinum wires. The wire has first of all to be cut up into the lengths required. A deposited or paste joint can then be made without any further work on the platinum, but it is better to prepare the platinum in some way, or the cement will not have a good hold upon the wire. The plain wire is too smooth, and should be roughened or shaped so that the carbon cement has something to hold on by. The wire may be twisted into a spiral, forming a socket into which the end of the filament is put. The spiral can be formed by twisting the wire with a machine like that shown in Fig. 13.

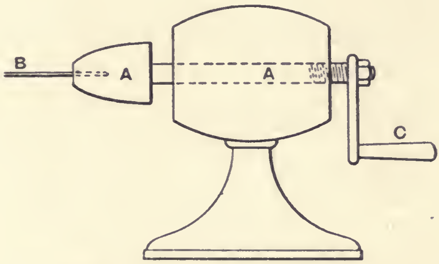


FIG. 13.—Wire-Twisting Machine.

A A is a spindle, with a needle B at one end and a handle C at the other. There is a screw thread on A which allows the needle to be rotated the same number of times (two or three usually) for each wire. The end of the platinum wire is inserted in a small hole close to the needle. The wire is held tightly, and the spindle rotated by the handle, thus twisting the wire two or three times round the needle. The wire is then slipped off the needle, straightened, and finished off with a small pair of pliers.

If a socket is required, it is better to make the tube form, which uses less platinum than the spiral. To make the tube, the wires are first flattened out for an eighth of an inch or so at the ends. This can be done by means of rollers, which may be arranged to cut the wires at the same time. The wire, being fed into the machine in a continuous length, is cut

and flattened at one operation. The wires are then drawn through an ordinary wire draw-plate, which bends the flattened ends round into a tube. Before drawing through the plate, the flattened ends must be annealed by heating to redness in a Bunsen gas flame. If this is not done these ends will be pulled off instead of being formed into a tube. The filament is slipped into the socket, which is then squeezed upon it so as to hold it tightly. It is convenient to have the wires joined together by a bridge of glass before mounting in the socket, but it is not necessary.

If a butt or lap joint is to be made, the wires may be nicked near the end, so as to form an indentation by which the deposit can hold on. An excellent way of making a butt joint is that which is adopted by the Edison-Swan Company. A small, flat head, like a pin-head, is formed on the end of the wires. The end of the filament is placed against the centre of this head, and carbon is deposited over the head and the end of the filament. As the carbon is deposited so as to completely cover up the head, it forms a very secure joint. Deposited carbon will always hold tightly to the filament. For filaments taking up to an ampere of current, platinum wire of 0·014in. diameter is generally used. The Author has, however, known lamps taking several amperes to work perfectly well with this size of wire. For currents above one ampere larger wire should be used, and for more than five amperes several small wires are better than one large one.

The deposited carbon joint, as has already been mentioned, is made by strongly heating parts of the wires and the filaments by a current of electricity in a hydrocarbon vapour or liquid. The hydrocarbon is decomposed by the heated wire and filament, and a deposit of carbon upon the part heated is the result. In order to make such a joint it is necessary to fix the wires and filament in a machine which will make the necessary electrical connections. For filaments which are mounted in sockets the illustration Fig. 14 shows a convenient apparatus. The filaments being already clamped in the sockets on the wires, the wires are inserted under the springs A A, which can be raised by the pins B B (one only of these two springs with its pin can be seen in the illustration). The metal pieces C C, which turn stiffly about D D, are turned so that

the parts E E lightly press on the filament at a short distance beyond the platinum wire. The spring contact pieces F F are then lowered by the thumbscrews G G, so that they press upon the filament just over the places where it is supported by E E. A good contact is thus secured upon the filament without straining it. The body of the instrument, K, may be made of wood, and all the metal pieces may be of brass. Between the springs A A and the wood K are metal strips L L, which are fastened to K and are continued beyond K for some

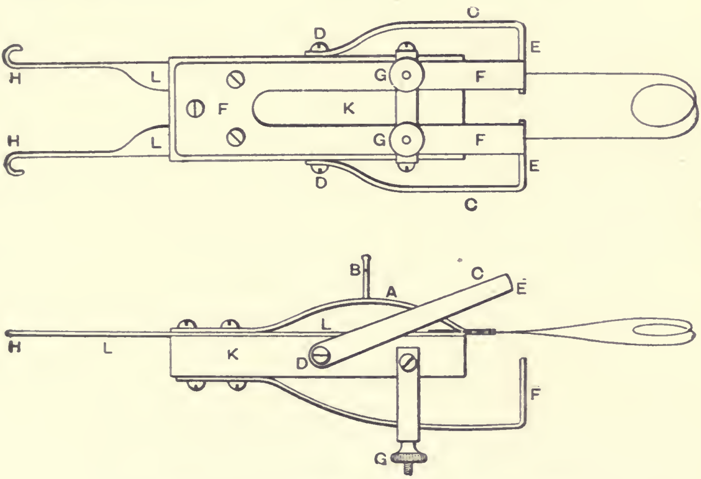


FIG. 14.—Cementing Machine for Socket Joints.

distance. The current enters and leaves the apparatus by these pieces, which may conveniently terminate in a hook H. The path of the current is from the hook H along L and A to the platinum wire, along the filament to F, round F to the other side of the filament and to the other platinum wire, and back through the corresponding parts on the other side of the instrument to the second hook H. The larger part of the filament is thus short-circuited by F F, and the process is consequently sometimes called "short-circuiting."

If a butt or a lap joint is to be made, the machine must be arranged so that the filament can be easily and quickly

adjusted to its position opposite the platinum wires. For this purpose an instrument like that shown in Fig. 15 will answer the purpose.

There are two sets of spring contacts A A and B B, mounted on a wood block C, of which that part between the two sets of springs is cut away to the depth of about half an inch. The electrical connections are made to the spring contacts A A by means of the wire D and a corresponding wire on the other side of the instrument. The platinum wires are first clamped in A A, and the filament is then put into B B, so that its ends touch the ends of the platinum wires. The part which gets heated by the current is, of course, that between the two sets of clamps. The block is cut away to allow of a free circulation of the hydrocarbon.

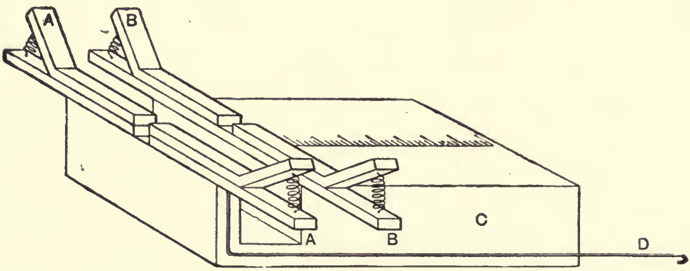


FIG. 15.—Cementing Machine for Butt Joints.

When the deposit is obtained from a hydrocarbon vapour, the apparatus, either that of Fig. 14 or Fig. 15, with the filament and wires already placed in position, is hung on a support, which also conveys the current. This support is fixed on a flat circular stand, which has a groove running round it. This groove contains mercury, and forms an air-tight joint for the glass shade, which is placed over the apparatus. Common coal gas, enriched by passing over benzoline, gasoline, or ether, is led into the apparatus through the stand, and an exhaust pipe is also provided. The gas is turned on, and when sufficient time has been allowed for it to fill the enclosed chamber the electric current is turned on. A resistance is used, so that the current can be gradually increased as the deposit proceeds. The glass shade must be weighted, or other-

wise held down, or it may be lifted up by the gas inside. The current is regulated so that the pieces of the filament between the contacts and the platinum wires are brought to a bright red heat, and the deposit commences. It takes, however, a long time in this way to get a sufficient deposit upon the platinum, and it is, therefore, better to use a little carbon paste on the junction. A suitable paste may be made by mixing powdered carbon with a solution of dextrine or caromel, and can be applied with a small brush. If this is done the current will be increased much more quickly, and a sufficiently strong joint be obtained.

The liquid process is, however, more easily worked, and makes a more satisfactory joint. In this process the frame which holds the filament and platinum wires is hung on a support which also conveys the current, so that the part which is heated, and upon which the deposit is to be formed, is entirely below the surface of the liquid. Several filaments may be cemented at the same time, the frames being arranged in series, with a switch connected to each, so that any one of them may be cut out if necessary. It is more convenient to use a separate jar of liquid for each filament, though one large trough will answer the purpose. The jars are set in a metal or stoneware trough to catch any spillings of the liquid. It is also advisable that the whole of the bench at which the work is done be covered with zinc to prevent the wood from being soaked with the oil. An extinguisher, to cover over the whole of the trough containing the pots of liquid, should be provided in case of accident. There is, however, no danger from fire, unless very inflammable liquids are used. Any hydrocarbon liquid will produce a deposit on a carbon filament heated to redness below the surface of the liquid, though some liquids deposit very much more quickly than others. Vegetable oils, such as olive oil and linseed oil, produce a good deposit. They are, however, too viscous for use with very fine filaments, and the smoke which is produced has a bad smell. Turpentine deposits very rapidly, but the deposit is too soft. Benzoline or benzine rapidly deposit, but are too dangerous for ordinary use. Ether gives a rapid deposit, but, of course, cannot be used in the open. Mineral oils are generally used. The best kerosene oil gives a good and hard deposit, but is very slow.

Crude petroleum, a black liquid containing mineral oils of various densities and flashing points, answers the purpose very well. A satisfactory liquid may be obtained by mixing one which deposits rapidly with one which does so slowly, but gives a hard deposit; such a mixture, for instance, as four parts of best (high flashing point) kerosine to one part of turpentine. This mixture gives a sufficiently rapid and hard deposit, and is not dangerous to use. Even when the liquid has become very hot, a lighted match applied to the surface will be extinguished.

While the deposit is going on a stream of dark smoke rises from the liquid. This smoke will burn as it bubbles up out of the liquid if it be lighted, but it can easily be blown out again. To obtain a proper deposit the joint is maintained at a bright red heat. There is no danger of firing the liquid so long as the joint is kept below the surface, and the current turned off before it is lifted out. The liquid may be fired by carelessness on the part of the operator. If, for instance, a joint breaks, as sometimes happens through excess of current when the depositing is going on, and so breaks the circuit, the operator may take out the filament and put in another, having forgotten to turn the switch off. As soon as the form with the new filament touches the contacts the joint will light up, and if it is not below the surface of the liquid, it will certainly set fire to the oil, if it be an inflammable one.

The strength of current used in making a joint is many times greater than the joint will ever be called upon to carry afterwards. In order to join a filament six mils in diameter to platinum wires of fourteen mils with tube sockets, the deposit to extend for a tenth of an inch along each leg of the filament, about twenty volts will be required to start the deposition, *i.e.*, to make the ends of the filament bright red-hot under the oil. As the deposition of carbon proceeds, the ends of the filament become rapidly duller. The thickness of the filament is increased, and, therefore, the cooling surface, while the resistance is at the same time diminished; and as there is a regulating resistance in the circuit, having a considerable resistance compared with that of the joint, the current rises only a very little. It is, therefore, necessary to cut out some of the regulating resistance and increase the current, so as to keep the joint at a bright red heat. In this way the current

will be gradually raised to at least twelve amperes before the joint is large enough, with a sufficient amount of deposit on the platinum. The volts will fall as the current is raised. With the best kerosene oil it will take ten minutes to make this joint. If the operation be hurried by turning up the current too fast, the joint will probably break, and both the filament and the wire will be spoiled by the arc which will be formed at the break. With one-fifth part of turpentine added to the kerosene, the time occupied can safely be reduced to one minute and yet produce a good hard joint.

A circulation of air should be arranged in the room where the process is carried on, in order to carry the smoke and fumes away from the operatives. The fumes from mineral oils do not appear to be unwholesome as are those from animal or vegetable oils, although the smell is not altogether pleasant.

The resistance used for the purpose of varying the current may be composed of a number of carbon plates lying one against another, with a screw arrangement for tightening them ; or a water resistance may be used. The least troublesome way, however, is to use an alternating current with choking coils instead of resistance. An ammeter should be used, so that the operatives can watch the rate of increase of the current and cut it off at the right point. When the liquid is fresh, the current may be regulated according to the appearance of the red-hot joint, but when the liquid has been used for some time and becomes black, the hot joint cannot be seen. Even then, however, the regulation can be effected by watching the volume of the smoke which bubbles up. An ammeter is, however, more reliable.

The deposit formed on the platinum is due to the platinum being heated to the required extent more by conduction from the hot ends of the filament than by direct heating by the current. The deposit, consequently, does not reach far along the platinum, which is kept too cool by the liquid to decompose it.

After this process the filaments and platinum wires will be oily and must be cleaned. This is easily done, as regards the filament, by gently heating by means of current, while the platinum wires can be heated in a Bunsen or blow-pipe flame.

If a thick, sticky oil has been used for depositing from, it may be necessary to first wash the filaments in kerosine.

In making a paste joint, a drop of the carbon paste is applied to the ends of the platinum wires with a small brush, and the filament is stuck into the drop, which quickly dries and sets. The paste must then be heated to drive off the volatile substances with which the carbon powder is mixed, and the joint is made.

CHAPTER V.

FLASHING.

The process usually called "Flashing" will now be considered. It is a similar process to the one just described of making joints by the deposition of carbon. Carbon is deposited upon the whole of the filaments from either a liquid or gaseous hydrocarbon. The name of "flashing" was given to the process because the filaments used to be flashed, *i.e.*, lighted up and extinguished a number of times at short intervals, while in a hydrocarbon vapour. The actual flashing in this way is not necessary to the process except under certain conditions, and the term will here be used to mean the depositing of carbon on a filament by electrically heating it in a hydrocarbon liquid or vapour.

In the early days of lamp making, flashing was resorted to for the purpose of making the carbon filaments light up evenly along their length. Early filaments were not even, and would light up with bright and dull spots all over them. The process of flashing had the effect of reducing this unevenness, and, if carried on for a sufficient length of time, of entirely removing it. The reason is simple. The bright spots on the filament are mainly due to those parts having a higher electrical resistance than the rest, and the dull spots to a lower resistance. This variation in the resistance at different parts of the filament may be due to a variation in the specific resistance of the filament, or to a variation in the thickness, or a combination of both these causes.

Now, carbon is not deposited from a hydrocarbon until a certain temperature is reached, at which the hydrocarbon is decomposed, and, up to a certain point at any rate, the higher

the temperature the more rapidly does the deposition take place. Thus, when a spotty filament is lighted up in the presence of a hydrocarbon, the higher resistance parts, or bright spots, will be deposited upon before and more quickly than the rest of the filament. The result is that the resistance of those parts is reduced, and consequently they are less and less heated by the current, and are gradually reduced to the same brilliancy as the main part of the filament. As the current is increased so that the main part of the filament is hot enough to be deposited upon, its resistance will fall, and it will in turn be gradually brought down to the level of the dull spots.

Filaments are, however, now made by several processes which will light up perfectly evenly along their whole length, and, therefore, do not require flashing for the purpose of obliterating spots.

Another difficulty with early lamp-makers was to get all their filaments of the same resistance. The resistance of the carbon filaments would vary very considerably. Here, then, another use of the flashing process presented itself for reducing different filaments all to the same resistance. This can be done by connecting the filament during flashing with an ohm-meter, which will show the actual value of the resistance at any moment. When the resistance has fallen to the figure required, the current is cut off and the process stopped.

Another method is to measure the resistance cold. A three-way switch is used to connect the filament alternately to the dynamo and to a Wheatstone bridge, by which the resistance is measured cold, using, perhaps, only one or two volts. The "bridge" is set for the required resistance, and a key is depressed. A reflecting galvanometer is conveniently arranged to throw a bright spot of light in front of the operator, who on depressing the key watches the behaviour of the spot. If the resistance is still too high after the first application of the current, the three-way switch is put over again, and the filament is again lighted up and a further deposit is given to it, and so on until its resistance is brought down to the required figure.

The actual flashing current may be arranged to work a Wheatstone bridge. The resistances are constructed to with-stand, without undue heating, the currents which they will

receive, the filament itself forming one arm of the "bridge." A galvanometer with a conspicuous pointer can then be used and fixed where easily seen by the operator, who cuts off the current at the instant when the pointer indicates that there is no current passing in the galvanometer circuit.

Just as filaments are now produced free from spots without being flashed, so are they also produced all alike in resistance, so that flashing is not necessary for either of these two purposes. Why, then, do lamp-makers continue to use the process? The reason is that the carbon deposited by the flashing process under certain conditions is so much more durable than anything which can be produced by other methods, that it improves most carbons to give them even an exceedingly thin coating of deposited carbon. It makes them mechanically stronger, and prevents the disintegration of the filament from proceeding as rapidly as it otherwise would do.

There are, however, other effects of flashing which have to be reckoned with. One of these is that the filaments are thickened by the deposit and their surface is consequently increased. Another is that the deposited carbon may and usually does materially alter the emissivity of the surface; that is to say, the rate at which it will radiate light and heat. Thus flashing will at the same time reduce the resistance of the filament, enlarge the surface, and alter its emissivity.

Now, to be commercially successful, a lamp-maker must be able to turn out lamps which are very nearly all alike in candle-power and voltage, when run at the same temperature; or, rather, when run at the same voltage, the lamps must be equally bright, small differences in candle-power not being of great consequence. The lamp-maker has to aim at turning out the filaments so that, at the required voltage, whatever it may be, they are all equally bright and approximately of the same candle-power. Two or three per cent. variation in the voltage of the lamps is the maximum which should be permissable. A greater variation than this will be at once apparent to the eye by a difference in the brightness of the lamps. This is a much more important point than the actual candle-power, *i.e.*, quantity of light being given out by a lamp. A small difference in colour or brightness can be seen at once, whereas a difference of 10 per cent.

in the quantity of light given out by two lamps running at the same temperature does not attract attention; in fact, it can only be detected by the aid of a photometer.

Again, suppose we take two lamps running at different temperatures. Let one be running at two and a-half watts per candle-power, and be giving a light of ten candles, and the other at four watts per candle-power, and be giving fifteen candles. Nine people out of ten will tell you that the two and a-half watt lamp is giving more light than the fifteen candle-power one, simply because it is brighter. Small differences in temperature are readily seen, while small variations in the quantity of light are not noticeable. Hence a lamp-maker cares more about getting his lamps to run at the same temperature than at the same candle-power. A uniform temperature for all his lamps is the goal at which a lamp-maker has to aim.

Now, as lamps are run in parallel, he also has to make his lamps run at a uniform temperature at a certain voltage. These are the two fixed quantities. The temperature may be whatever he considers best for the particular filament which he makes, so long as it is the same for all, and the voltage must be the voltage of the particular circuit for which the lamps are intended.

The candle-power or quantity of light given out may vary to any extent among different lamps in one room, but if they are all at the same temperature they will look all right.

Some of the different effects produced by flashing will now be briefly considered.

To simplify the case as much as possible, it will be supposed that the filaments, after carbonisation, are all exactly alike in dimensions and in specific resistance, and in the nature of their surface or emissivity.

Carbon deposited on a filament from a hydrocarbon may be of a soft, sooty, or of a hard and dense kind. The latter is the only kind that is any use, and will, therefore, only be considered. Such carbon has a very much lower specific resistance than that of the filaments themselves. Consequently, with filaments of small cross section, a very slight deposit will reduce the total resistance very considerably. It is, therefore,

of the utmost importance that the process be arrested instantly the required resistance is reached. It is well known that the resistance of carbon falls as the temperature rises—the reverse of the behaviour of the metals. Roughly speaking, the resistance of an incandescent lamp at the temperature of the air is double the resistance it will be when running at the ordinary temperature. Suppose that the resistance during flashing is indicated by an ohmmeter, and the current be cut off when it has fallen to a given number of ohms; or let the circuit be arranged Wheatstone-bridge fashion, with a galvanometer to indicate when the required degree of resistance has been reached. If now a filament be flashed at a moderate temperature until the required resistance is indicated, and then another filament be flashed at a brighter temperature to the same resistance, and then the two filaments be made up into lamps and tested, they will be found to be quite different. At the same volts one will be brighter than the other. Why is this? Simply because the resistances were adjusted at different temperatures. If both are run at the same temperature the resistances will be found to differ. It is, therefore, obvious that this method of flashing to a certain resistance is useless, unless the flashing is done at the same temperature in all cases. The value of the method, therefore, depends on the skill of the operator in adjusting the strength of current by means of a variable resistance, so that the filaments are all flashed at the same temperature. It is difficult to do this correctly, as the filament is at a dazzling white temperature, and the operator's eye soon becomes unreliable. Of course, a darkened glass or spectacles may be used, but it is a question if the results are any better. Another trouble is that the glass receiver in which the filament is flashed becomes coated with a dark deposit which becomes thicker and obstructs more light with each filament that is flashed, and it must, consequently, be cleaned very frequently.

At first sight, it might appear that if the resistances of the filaments be measured cold instead of hot, the error due to different flashing temperatures would be overcome. Here, however, another difficulty occurs. Carbon deposited at one temperature is of a different quality from that deposited at another, one difference being that its resistance temperature

coefficient is not the same. Therefore, two filaments flashed at different temperatures, so that they measure the same resistance when cold, will be found to have different resistances when hot. In this case again, the results depend on the accuracy of the eye of the operator for reproducing the same temperature during the flashing of each filament.

Apart from these difficulties in flashing to a certain resistance, either hot or cold, there are many other ways by which the flashing may affect the ultimate evenness of the lamps. The deposit sensibly increases the thickness of the filaments, and consequently its radiating surface, and the thickened filament will therefore require a greater amount of electrical energy to maintain it at the required temperature. If the conditions of the flashing are reproduced exactly for each filament the thickening will be the same for all, and can be allowed for. If, however, a filament has been flashed to a certain resistance but has become thickened more than the amount allowed for, it will be found, when made up into a lamp, that although its resistance may be exactly what was wanted, yet it is dull when run at the voltage for which it was intended. If it be run to the proper brilliancy it will be found to be of greater candle-power than was intended.

Again, flashing almost invariably alters the emissivity of the filament, or its power for radiating heat and light. If the conditions are precisely reproduced in each case a definite emissivity can be calculated upon. If not, and there is a greater emissivity than was allowed for, the lamps will be dull at the voltage for which they were intended, and if the emissivity be less than that calculated upon they will be over bright.

It will now be readily understood that extreme care is needed in the process of flashing if uniform results are to be obtained. The actual amount by which the voltage of a lamp will be affected by any of these errors will be dealt with further on. In the meantime, some of the processes of flashing will be described.

The filaments may be flashed either before they are mounted or afterwards, or both before and after. Almost any hydrocarbon may be used, but for each one there will be certain conditions which will give the best results. Thus, one will

work best if the filament be made very bright indeed, and another may only require a moderate temperature. One may require to be at a considerable pressure, while another must be much rarefied.

It was stated in the chapter on "Mounting," that a heavy deposit is produced more quickly under a liquid than in a gas. For this reason it is best to flash in a gas, at any rate in the case of small-current filaments, as a thick deposit is not required. As a matter of fact, the deposition of carbon always takes place from the gas, even when done under the surface of a liquid. The liquid in contact with the filament is intensely heated, and by the time the filament is red hot the liquid round it is boiling so violently that the vapour alone comes into contact with it. It is this vapour which is decomposed and produces the deposit on the filament. There is produced in this way a hydrocarbon vapour of great density surrounding the filament, and hence the rapid deposition of carbon. In reducing the resistance of a filament by flashing, it is necessary that the process be not too rapid, or a slight error in stopping the current at the right moment will considerably overstep the mark. For thin and high-resistance filaments, such as for 100-volt, 16-c.p., or 8-c.p. lamps, the process must be made much slower than for filaments for lamps which will take several amperes of current. It is consequently easier to flash low-current filaments successfully in a gas than under a liquid, and the gas may further be considerably rarefied.

Ordinary illuminating gas can be used for flashing in at atmospheric pressure. In this case the apparatus required is very simple, as shown in Fig. 16. A is a glass bell jar ground flat on the top and bottom, so that with the aid of a little grease it stands gas-tight on the brass base-plate B. Through this plate pass the tubes C and D, one being the gas supply and the other the exhaust pipe. E is a plate made of hard wood, which carries two spring clips, G G, for holding the filament H. On the upper side of this plate are two metal contact plates, F F, connected with G G, the whole of this arrangement being removable. A spring contact arrangement, K, makes the electrical connection with F F, and at the same time holds the plate E firmly upon the top of the bell jar so that it is gas-tight. To work the apparatus, a filament

is put into the clips which are then inserted in the jar, and the spring contacts are let down on the top. Gas is then turned on through C, and air and gas escape through D. In a short time there will be very little air left in the jar, and the current may be turned on and gradually increased by means of a regulating resistance, until the filament is brightly lighted up. The deposition of carbon now begins, and the resistance of the filament becomes lower, and it gets much

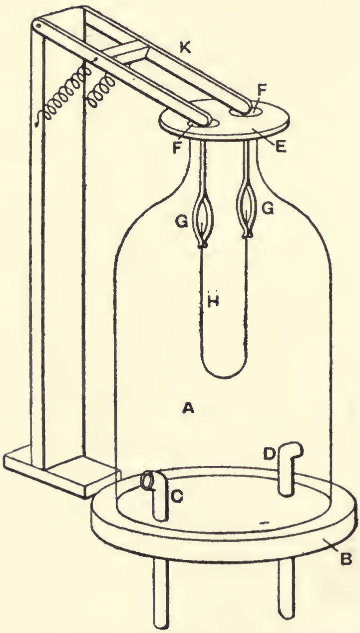


FIG. 16.—Apparatus for Coal Gas Flashing.

brighter. This, perhaps, at first sight appears curious, as it will be remembered that when depositing on a joint the joint became dull. Whether the filament or joint becomes brighter or duller as the deposition proceeds simply depends on the amount of resistance in series with it. In starting a high-resistance filament it probably requires all or nearly all the available electrical pressure to light it up, and consequently the regulating resistance is mostly if not all cut out. As the resistance of the filament decreases the current increases, while

the volts remain the same, or nearly so. The filament consequently becomes brighter, and the temperature must be kept down by adding resistance. On the other hand, if, when the filament is lighted up, there is a resistance in circuit greater than the resistance of the filament, it will become duller as the deposition proceeds, for, though the current through it will increase, the difference of potential at the ends of the filament will decrease, so that there is less power being expended in it. Some of the regulating resistance must consequently be cut out to keep the filament bright. The total E.M.F. used should be just sufficient to light the filament up to the required brightness for the deposition, without any extra resistance in the circuit. As the deposition proceeds and the resistance of the filament falls, resistance must be added to the circuit in order to keep the temperature of the filament constant. More and more resistance has thus to be added until the added resistance is equal to one-fourth of the resistance of the filament when first lighted up. When this point is reached the resistance of the filament itself will also be one quarter of its original resistance. If the deposition is continued beyond this point, the added resistance is gradually cut out of the circuit again, as the filament henceforth gets duller instead of brighter as its resistance continues to fall. It is here assumed that the total E.M.F. is kept constant, and that the same number of watts are expended in the filament throughout the process in order to maintain it at the constant temperature. As a matter of fact more power is required as the process proceeds, owing to the increase in thickness of the filament, so that the greatest amount of extra resistance required will not be so much as one-fourth of the original resistance of the filament. It is not often that filaments are flashed to the extent of reducing their resistance to one-fourth of the initial value.

The filament must, therefore, be kept at the required brightness by the variable regulating resistance in series with it. When the ohm-meter or galvanometer indicates that the required resistance is reached, the current is immediately turned off, and the filament is taken out and a fresh one put in.

The process of flashing in coal gas at atmospheric pressure is not a good one. It is too rapid. The deposit is very rough,

and is apt to be sooty. A quantity of smoke is produced, and the glass jar is soon obscured.

It is better to reduce the pressure by means of an exhaust pump. Instead of the exhaust pipe D (Fig. 16) being led into the open air, it is connected through a stop-cock to a mechanical exhaust pump. Between the stop-cock and the receiver is connected a syphon mercury vacuum gauge. When the filament has been inserted the vacuum cock is turned, and a vacuum is produced in the receiver, which should be exhausted until the vacuum gauge shows a difference in the height of the two sides of the mercury of about 1in. The vacuum cock is then turned off and gas is admitted by the other cock until the vacuum is reduced to about 6in. difference in level on the gauge. The filament may then be treated as before. The deposit will be less rapid and of a better kind, being harder and whiter and not so rough. If it is still too rapid, it can be made slower by reducing the pressure again after the gas has been let in. This process may also be varied by passing the gas over ether, gasoline, benzine, &c., but better results can be obtained by methods which do not use illuminating gas at all.

The vapour of benzine, ether, gasoline, or other volatile hydrocarbons may be used alone. Whichever is used, the precise treatment will be different in each case, each hydrocarbon requiring to be used at a different pressure to produce the best results.

A method in which the vapour of gasoline may be used may now be described. This liquid is much used in America for the manufacture of gas for illuminating and other purposes in situations where coal gas is not available. It is one of the lightest and most volatile liquids obtained from petroleum, having a specific gravity of only about 0·66. It has a very disagreeable smell, and is apt to vary somewhat in its composition, some samples being more volatile than others. For this reason it is better to use "standard pentane," a liquid prepared specially for use in the Harcourt standard lamp. It is simply gasoline purified. It has no bad smell, and is always of the same quality. It has a specific gravity of about 0·63. It is, of course, a much more expensive liquid than most hydrocarbons, but it can be used almost up

to the last drop without waste, as it is entirely closed up and only admitted to the flashing chamber in exact quantities required for use. As it is extremely volatile it is necessary to keep it in a well stoppered bottle, with the stopper fastened down, or it will very soon disappear.

The process about to be described, in which pentane is used, is capable of giving the filaments a very thin coating of deposited carbon. A circular brass base-plate, A (Fig. 17), turned perfectly true and free from flaws, is fixed to the bench.

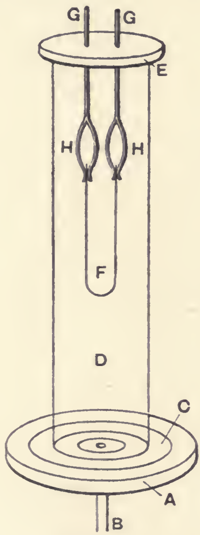


Fig. 17.

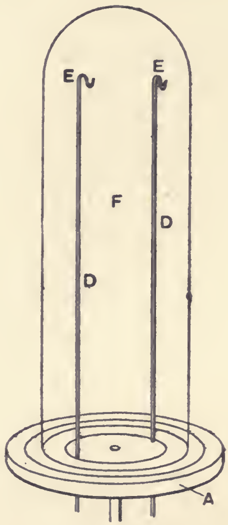


Fig. 18.

Apparatus for Pentane Flashing.

A small hole, $\frac{1}{8}$th of an inch in diameter, passes through the centre. Into this hole is screwed and soldered the end of a brass tube B, which passes through the bench or table. Upon A is a flat rubber ring, C. The glass receiver D, which may be about 11in. high and $2\frac{1}{2}$in. in diameter, stands on the rubber ring. The whole of the clip arrangement on the top of the receiver can be lifted off. It consists of a vulcanite disc, E, underneath which is another rubber ring. Through the disc pass two brass rods, G G, ending in the spring clips H H, for holding the filament F. Four of these apparatus

may be fixed close to each other on the same bench, and can be operated by one person.

Another arrangement is that shown in Fig. 18. Two metal rods, D D, pass through the base plate A, from which they are insulated, and terminate in the hooks E E. A glass shade, F, covers the whole and stands on the rubber ring on A. The filament is held in a clip such as that shown in Fig. 19. The metal parts C C are insulated from each other by mica, A, bound round with metal B. The clip is hung by the eye-pieces D D on the hooks E E (Fig. 18). Mica should be used for the insulation, as other insulating materials may not be able to stand the heating to which they will be subjected during a prolonged flashing.

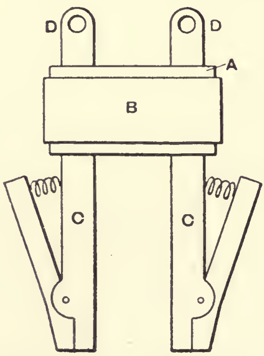


Fig. 19.—Clip for Holding Filament during Flashing.

Fig. 20 is a diagram of the vacuum connections. A A′ B B′ are the bases on which the receivers stand. The arrangement shown is such that A A′ can be worked while B B′ are being pumped. There is a syphon mercury vacuum gauge C C C C, about 6in. or 8in. high, for each receiver. This kind of gauge is necessary. A barometer tube gauge is too large and clumsy, and is apt to get broken when the vacuum is destroyed, owing to the impact of the mercury with the top of the tube. Moreover, the scale must be a movable one, so that it can be raised or lowered according as the barometer rises or falls, or the true state of the vacuum in the receivers cannot be known. A syphon gauge always shows the actual state of the vacuum, whatever the atmospheric pressure

happens to be. D D′ are two-way cocks connecting A to A′ and B to B′. E E′ are three-way cocks which will connect A A′ or B B′ either to the air by F F′, or by the three-way cock G to the pentane resevoir H, or to the vacuum pump K. The method of working is as follows :—

Filaments to be flashed having been put into the receivers on A A′, the cock D being open ; the cock E, as shown in the diagram, connects A A′ to G, and through G to the vacuum

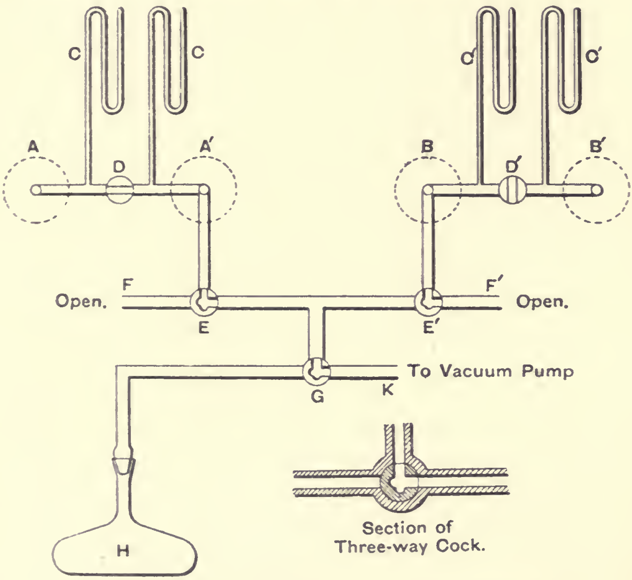


FIG. 20.—Vacuum Connections for Pentane Flashing.

pump, which may be at a distance in the engine room of the factory, and be driven by power. A vacuum is soon produced in the receivers on A A′, and when it arrives at about 6in. pressure of mercury its progress can be watched on the gauge C C.

It is essential in this method of flashing that all joints, pipes, and cocks be absolutely airtight. It might be supposed that arrangements such as shown in Figs. 17 and 18 would not be airtight. Standing with their own weight on the base-plates the glass cylinders would not be tight, but, as soon as the vacuum is turned on, the pressure of the air forces the cylinder

so tightly against the rubber rings that the arrangement does not leak, and, if properly made, it will hold a vacuum for hours. Of course, the arrangement shown in Fig. 18 with only one rubber joint is less likely to leak than the one (Fig. 17) where the filament is inserted through the top of the cylinder.

The vacuum is applied until the difference in level of the mercury in the gauges is about half an inch. This is as far as most mechanical air-pumps will go in practice. The cock G is then turned, disconnecting the receivers A A′ from the vacuum pump, and connecting them with the reservoir H, which has previously been partly filled with pentane. Pentane vapour now passes from H along the tubes into the receivers A A′. This is apparent by the increased pressure indicated by the gauges C C. The vapour should be allowed to enter until the gauges show 5in. difference in level. The cock G is then turned back again, connecting A A′ with the vacuum pump, and the vacuum is again reduced to about 1¼in. by the gauges. The cock E is then turned so that A A′ are disconnected entirely. The cock E′ is now turned so that B B′ are connected through G to the vacuum pump. The condition of A and A′ is now the same, and the cock D is turned, so that A is shut off from A′. Current is now applied to the filament in A. The increase in temperature of the gas in the receiver, produced by the heating of the filament, causes increased pressure, and the gauge shows a decreasing vacuum. The filament is brought to a bright white heat, at which it is maintained by means of the regulating resistance, until the indicator which is used shows that it has received a sufficient coating of carbon. The filament in A′ is then treated in the same way. The cock D may then be opened, and E turned so as to admit air through F into A and A′. The filaments are then taken out and fresh ones put in. The same process is then repeated with the filaments in B and B′. While the flashing is going on in one side of the apparatus the other side is being pumped.

This may appear a complicated arrangement of pipes and stopcocks, but with a little practice it can be worked very quickly. With the apparatus shown in Fig. 18, the electrical connections with the different filaments is made by

means of a switch, while with the other form (Fig. 17) one clip on the end of a flexible wire makes connection to the wires G G. By this latter method the chances of turning the current on to the wrong filament are less than with the switch arrangement, as the operator is apt to forget to put the switch over, whereas in the other arrangement the clip must be removed from the top of the apparatus before the filament can be taken out.

A quicker method of flashing is to use a large receiver in which six or eight or more filaments can be flashed one after the other in the same vapour. This, however, is not a good plan, as the conditions are then different for each one. The only way to treat the filaments exactly alike is to do them separately. For this reason the cocks D D′ (Fig. 20) are put between the receivers, so as to prevent the gas and smoke from one entering the other as would otherwise happen.

Immediately below A A′ B B′ is a bulb filled loosely with cotton wool to act as a filter, so that pieces of filament and dirt may not accumulate and block the pipes. There should also be another filter between G and the vacuum pump. The tubing and cocks may be either of metal or glass. The latter are more easily obtained and maintained vacuum-tight; but they are, on the other hand, more liable to breakage. Connection between the cocks and tubes can be made by rubber "vacuum-tubing," the glass or metal tubes being first greased with vaseline.

The brown coating which makes its appearance on the glass receivers during flashing can be easily cleaned off with a rag wetted with methylated spirit.

The electrical connections will be in accordance with the method of indication adopted, either for flashing to resistance measured hot or cold, or any other system. Care should be taken in arranging the apparatus that the operator shall not be liable to receive shocks A mercury double-pole switch which is normally held off by a spring is recommended, so that the apparatus is only connected to the dynamo while the switch is held on. The current is left on continuously while the depositing takes place.

The deposit of carbon produced by this method is hard and white, and of low specific resistance. By using a greater

pressure and quantity of vapour, pentane will give carbon varying from the hard white variety to a soft black one.

The Author is not aware that any systematic experiments have been carried out for the purpose of discovering what is the best amount of deposit to give the filaments. Any thickness can, of course, be given by prolonging the process.

One use of the process of flashing, not yet mentioned, is that one size (diameter) of filament may be made to do duty for lamps which are to take currents varying considerably in amount from each other. Thus, a filament suitable for a 100-volt lamp may by flashing be made into a 50-volt of the same candle-power, the one size of filament being available for all lamps with currents falling within such range. It seems probable, however, that one particular ratio of thickness of deposit to thickness of filament will give the best results for all sizes of the same filament flashed by the same method. Experiments of this sort are, however, very tedious to carry out, as conclusions can only be arrived at by life tests of a number of lamps of each of the variations.

The practical limit of the use of one size of filament for various currents is, however, determined by the time taken to flash. The longer the time the more costly will be the process, as fewer filaments can treated be by each apparatus and operator. The cost of a long flashing will soon mount up, and be greater than the extra trouble of making different sizes of filaments at first. Double the time of flashing means half the number of filaments, or twice the apparatus and number of operators.

Provided that the receiver of the flashing apparatus is large enough to hold plenty of hydrocarbon vapour, the thickness of deposit is proportional to the time during which the filament is lighted up. This is not correct for a very prolonged flashing, as the hydrocarbon vapour becomes impoverished and works slower and slower, but with a properly proportioned receiver it may be taken as being so within the time which can be allowed for the flashing. Time really fixes the limit to the amount of flashing. The pentane method described will produce a good and even deposit in from twenty seconds to one minute. The conditions can be arranged so that the deposit proceeds at the rate of about 0·00001in. per second.

In thirty seconds there will be then a good deposit 0·0003in. thick. A coating of this thickness will be just as smooth as the filament upon which it is deposited. Prolonged flashing gives a rougher deposit which may have a varying emissivity, and, therefore, a thin deposit is better. It is most convenient in practice to give the same thickness of deposit for all sizes of filament. The same time will then always be taken in flashing, whatever the size of filament. The size of filament must, therefore, be varied according to the current it is to take. No one size should be used for filaments taking different strengths of current, except within very narrow limits.

The E.M.F. required to flash filaments depends upon their length, thickness and specific resistance. For a 100-volt 16-c.p. filament from 200 to 300 volts may be required at starting, and as much as 1·6 ampere may be sent through the filament during the flashing when it will only take 0·64 ampere when finished. This great difference is due chiefly to the cooling effect of the convection currents within the receiver, which are, of course, absent in the finished lamp. When flashing at atmospheric pressure or under a liquid the difference is much greater. If the filaments are not properly carbonised before flashing, a much greater electrical pressure may be required to light them up in the first instance than that given above.

As already mentioned, the method of flashing filaments to a certain resistance, even when it is accurately done to the hot resistance, does not produce uniform results in voltage unless the size and emissivity of the filaments are also uniform. There is, however, another method in which the size and emissivity do not matter within certain limits. The filaments are flashed directly to voltage, and the candle-power and resistance may take care of themselves. Unfortunately, however, the eye of the operator has to be depended upon for producing and maintaining the right temperature even more accurately than when flashing to resistance. The quantity of hydrocarbon vapour, and particularly the pressure, must be exactly the same for each filament. A voltmeter is connected so as to indicate the volts at which the filament is being run. The current is turned on, and the filament is brought as quickly as possible up to the required brightness. Suppose that the filaments are for

100 volts and 16-c.p.: the voltmeter indicates, say, 200 volts. As the deposition proceeds the filament falls in resistance, but by means of the regulating resistance it is kept at the same brightness. The indication of the voltmeter is all the while gradually falling, and when it reaches, say, 170 volts the current is cut off. Now, provided that the conditions of temperature or brightness and the amount and pressure of the hydrocarbon vapour are the same in each case, it does not matter whether the filaments are 15, 16, or 17-c.p. ones; if the process is stopped when the voltmeter indicates 170 volts they will be alike in voltage when made into lamps, 170 volts in the flashing receiver being the corresponding value for 100 volts in the properly exhausted lamp. The actual voltage at which the current is to be cut off must, of course, be found by trial in the first instance for the particular apparatus and conditions employed. The degree of exhaustion in the receiver must be accurately reproduced each time. The greater the pressure the greater will be the E.M.F. required. A similar method can be used for making lamps to work at the same current, an amperemeter being used instead of a voltmeter.

Hard, white, deposited carbon has only about one-tenth of the specific resistance of carbon made from amyloid, the resistance of the deposited carbon of that kind being about 350 microhms per cubic centimetre, and that of amyloid carbon 3,500 microhms at a temperature of from 6 to 2 watts per candle power.

At the ordinary temperature of the air the deposited carbon is about two and a-half times greater, and the amyloid variety one and a-half times only.

It will thus be understood that the ratio of the cold resistance to the hot resistance of a flashed filament depends entirely on the ratio of the amounts of the two kinds of carbon of which it is composed, a much-flashed filament having a larger ratio than one only slightly flashed. The resistance of a filament measured cold gives no indication of its hot resistance unless that ratio is known. The most usual ratio is about two to one, though it is often above or below that amount. The specific resistance of arc-lamp carbons (cold) will vary from 13,000 microhms per cubic

centimetre to less than that of amyloid, according to the method of manufacture, moulded carbons having a higher specific resistance than squirted ones.

Different kinds of carbon have different emissivities—that is, they radiate heat and light at different rates, so that, at a given temperature, carbons of the same size but of different makes require different amounts of power expended in them in order to maintain that temperature. This curious property appears to be connected with the nature of the surface only, and has nothing to do with the material underneath the surface.

It is well known that a hot polished copper rod, if covered with lamp black will cool much more rapidly than a similar rod not blackened. In the same way a hot lamp filament with one kind of surface will cool faster than a similar filament with another kind of surface. A filament made of amyloid carbon will cool faster than the same filament if it be flashed in pentane in the way described. Suppose that an amyloid carbon filament be made into a lamp and tested, and that it is found that at 4 watts per candle power it takes 84 watts and gives, consequently, a light of 21 candles. Let the same filament be taken out of the lamp and flashed a very little by the pentane process, and then be made into a lamp again and tested. Let it be run at the same temperature as before, and it will be found to give only 15 candles and take only 60 watts. Now that it is flashed and has a different kind of surface it loses heat much more slowly, and a less expenditure of power suffices to maintain it at the former temperature. It must be particularly noticed, however, that there is a corresponding decrease in candle power. Let it be run at its original candle-power (*i.e.*, 21) and it will be found to take about 68 watts, equal, that is, to about $3\frac{1}{4}$ watts per candle, considerably less power than before flashing. Many people have supposed that results like this indicate that the flashed filament is a more efficient one than the unflashed. This, however, is not at all the case. The filament now giving 21 candles is at a higher temperature than it was when giving that candle power before being flashed. If it had not been flashed at all, it could have been equally well run at this temperature and efficiency, only it would then have given about

28 candles and have taken about 90 watts. The filament has simply become less emissive: it radiates more slowly.

The extent of surface of filaments will vary with different kinds of surfaces from 6,000 to 10,000 square mils per candle-power at the temperature of 4 watts per candle-power (equal to 100 to 170 c.p. per sq. in.). When run up to the temperature at which the best carbon begins rapidly to disintegrate (0·8 watt per candle-power) as much as 1,900 c.p. per sq. in. may be reached. The crater of an arc-lamp carbon is said to give about 45,000 c.p. per sq. in.

The change in emissivity produced by flashing gives an additional reason for carefully reproducing the conditions under which that process is carried out for each filament so that they may all come out alike.

The actual amount of the error in the voltage of the lamps produced by the several causes mentioned will now be considered.

An error in the thickness of a filament is a serious one. Suppose that a filament for a 100-volt 15-c.p. lamp at 4 watts per candle-power (= 60 watts total) should be 6 mils in diameter, but that the conditions of flashing have not been quite right, so that the diameter comes out at 6·4 mils, an increase of 6·6 per cent. in diameter, and therefore in surface. The filament will now require 6·6 per cent. more energy, and will be increased a like amount in candle-power. It will take 64 watts and give 16 c.p. But it was flashed to the resistance for a 15-c.p. lamp (166 ohms), not for a 16-c.p. one. Consequently, it will take 103·2 volts and 0·62 ampere, to give the right temperature. Or if run at 100 volts it will give only about 13·5 candles, and an efficiency of $4\frac{1}{2}$ watts per candle-power.

It will be noticed that, though the increase in diameter is 6·6 per cent., the increase in voltage is only about half that amount, the error being divided between the E.M.F. and the current. The percentage error in voltage will be about one-half that of the diameter for ordinary variations.

With regard to errors in emissivity due to the conditions of flashing being wrong, the effect is exactly the same as for errors in thickness, an increased emissivity having the same effect as an increase in diameter. A similar result will be

produced if filaments are mounted with wrong lengths. This is usually looked upon as a less serious matter than differences in thickness, as it is supposed to be easy to mount filaments

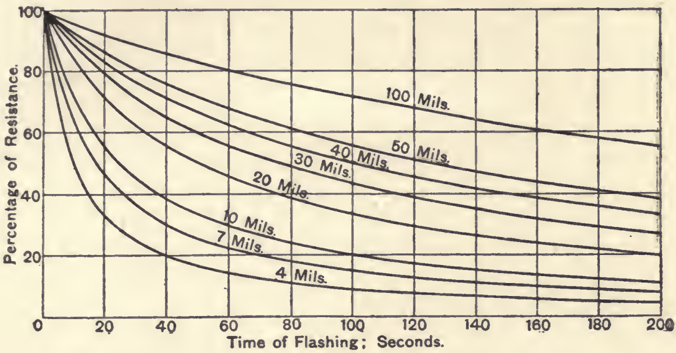


FIG. 21.—Curves showing Effect of Flashing on the Resistances of Filaments of Various Diameters.

to the proper length. Suppose a filament is to be 5in. long. One per cent. is 0·05in.—that is to say, it must be mounted with an error of not more than 0·025in. on each leg, in order

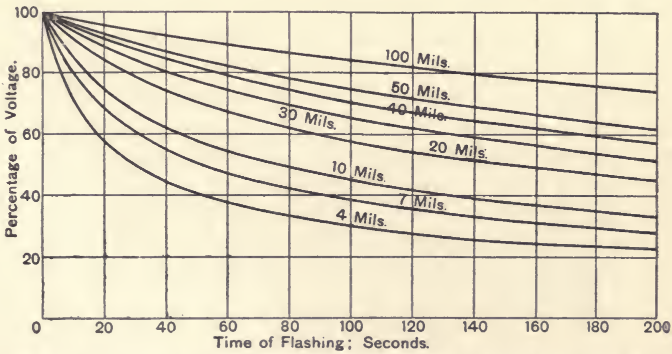


FIG. 22.—Curves showing Effect of Reduction in Resistance, due to Flashing, on the Voltage of Filaments of Various Diameters.

to be within 1 per cent. It is, therefore, very important to be exact in the matter of length.

With errors of resistance the same kind of result occurs as with errors in surface. One per cent. error in resistance will

produce only about one-half per cent. error in voltage. This must not be understood to apply to very large differences in resistance. For instance, a 50 per cent. reduction in resistance gives more than 25 per cent. reduction in volts. The actual

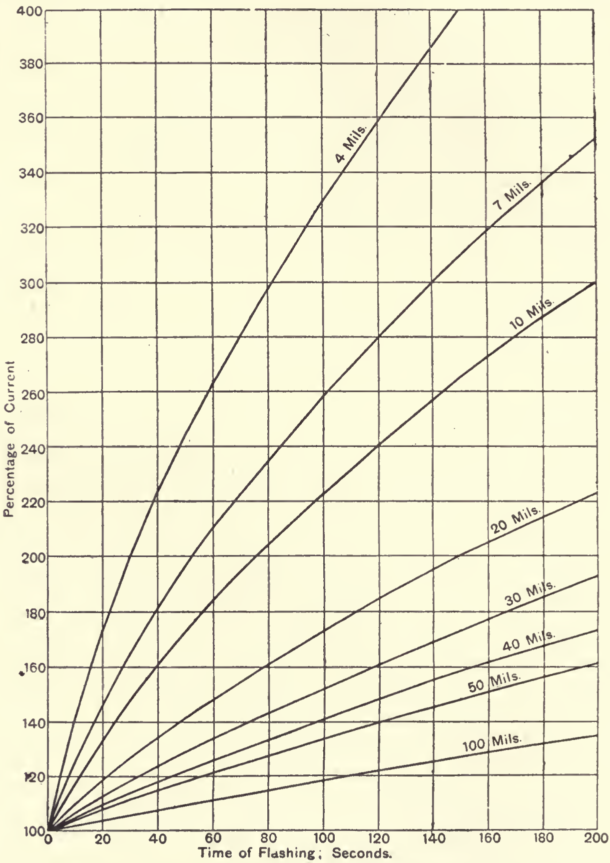


FIG. 23.—Curves showing Effect of Reduction in Resistance, due to Flashing, on the Current for Filaments of Various Diameters.

effect on the volts and current of a gradually diminishing resistance is shown in the accompanying curves, Figs. 21, 22, 23. The resistance is supposed to be diminished by flashing, the thickness of the deposit of flashed carbon being

considered as proportional to the time of flashing, the rate of flashing being such that a 4-mil filament is reduced 50 per cent. in resistance in ten seconds.

It must be understood that the effect of reduction in resistance alone is shown in these curves. The actual results of flashing, taking into consideration the change in resistance, emissivity and thickness, are fully dealt with in a subsequent chapter.

It has been shown that the time of flashing is an important consideration, and that it is better to flash always to about the same length of time, and to use filaments of different diameters which will permit of this being done, than to use only a few sizes of filaments and to vary the time of flashing.

It is therefore necessary to consider the relation of the sizes of filaments to the candle-power, voltage and temperature at which they are to be run.

CHAPTER VI.

SIZES OF FILAMENTS (UNFLASHED).

A HOT BODY may lose heat in three ways: (1) by conduction to another body with which it is in contact; (2) by convection currents in the medium by which it is surrounded, or (3) by radiation.

The filament of an incandescent lamp practically loses heat by radiation alone. Some is lost, no doubt, by conduction along the supporting wires, whence most of it is radiated at a lower temperature, a little being conducted away to the fastening outside the lamp. The proportion lost by conduction in this way is insignificant, except, perhaps, in the case of large current small candle-power lamps, and need not, therefore, be considered. In a properly exhausted lamp the loss by convection will be practically nil. Radiation, therefore, may be considered to account for the whole of the loss of heat.

The rate of loss of heat of a conductor by radiation is proportional to its surface. When a constant temperature is maintained in the conductor, the rate of loss of heat must be equal to the rate at which heat is generated in the conductor. If heat is generated at a greater rate the temperature will rise, if at a less rate it will fall.

If the same temperature is to be maintained in different conductors, the extent of surface of those conductors must be proportional to the rate of generation of heat within them. The rate of generation of heat in lamp filaments is measured in watts. Consequently, in order to maintain the same temperature in different sized filaments, the extent of surface of the filaments must be proportional to the watts expended

in them; or, *vice versâ*, the watts expended must be proportional to the extent of the surfaces of the filaments. The filaments must, of course, be in a good vacuum, and be of like emissivity.

The relation of the power expended to the extent of radiating surface is the ruling factor upon which everything else depends in determining the size of the filaments. With filaments of the same emissivity this relation will be constant for any given temperature, no matter whether the filaments be long and thin or short and thick, or whether they are circular or flat, solid or hollow.

As a rule, filaments are circular in section and solid, not tubular, and this kind will, therefore, be first considered.

Circular Filaments.

Let d = the diameter of the filament,
l = ,, length ,, ,,
r = ,, resistance ,, ,,
s = ,, surface ,, ,,
c = ,, current ,, ,,
and $c^2 r$ = ,, power spent in the filament.

Now, as the power spent is proportional to the surface, we have

$$c^2 r \propto s;$$

the resistance r is proportional to the length l and inversely proportional to the square of the diameter, or

$$r \propto \frac{l}{d^2}$$

(unflashed filaments are, of course, being considered), and the surface s is proportional to the diameter, multiplied by the length, or

$$s \propto d\,l.$$

Therefore, $$c^2 \times \frac{l}{d^2} \propto d\,l,$$

which simplifies into $$c^2 \propto d^3,$$

or $$c \propto d^{\frac{3}{2}},$$

and inversely $$d \propto c^{\frac{2}{3}}.$$

It is thus apparent that the diameter of the filament must be proportional to the $\frac{2}{3}$ power of the current, or that the

current must be proportional to the $\frac{3}{2}$ power of the diameter. The length l disappears from the equation, and we see that for any given temperature of the filament the diameter is determined solely and only by the current which it is to carry. To make practical use of this result we must write the equation

$$d = a\,c^{\frac{2}{3}},$$

where a is a constant the value of which depends on the specific resistance of the filaments, the emissivity, the units employed, and the temperature at which the filaments are to be run. It will be the same for all filaments made by the same process. Its value must be found in the first instance by trial. With amyloid carbon at a temperature of 4 watts per candle-power and the diameter measured in mils ($\frac{1}{1000}$ in.), and the current in amperes, its value will be about 10. For convenience it will, therefore, be considered to be 10.

For example, find the diameter for the filaments for three lamps a, b and c, to run at 4 watts per candle-power.

(a)	to be	100	volts,	8	c.p.,
(b)	,,	100	,,	16	,,
(c)	,,	60	,,	32	,,

First calculate the current which the lamps will take.

Lamp (a)	is to take	32	watts,	and therefore	0·32	ampere,
,, (b)	,,	64	,,	,,	0·64	,,
,, (c)	,,	128	,,	,,	2·13	,,

therefore for (a)

$$d = ac^{\frac{2}{3}}$$
$$= 10 \times 0{\cdot}468,$$
$$d = 4{\cdot}7 \text{ mils.}$$

,, ,, (b)

$$d = 10 \times 0{\cdot}742,$$
$$d = 7{\cdot}4 \text{ mils.}$$

,, ,, (c)

$$d = 10 \times 1{\cdot}655,$$
$$d = 16{\cdot}5 \text{ mils.}$$

Having thus found the diameters, the next thing to do is to find what length the filaments must be.

As the surface of the filaments must be proportional to the watts, and therefore to the candle-powers, and is also proportional to the length multiplied by the diameter, we have

$$l \times d \propto \text{c.p.},$$

or $$l \propto \frac{\text{c.p.}}{d},$$

or $$l = b\frac{\text{c.p.}}{d},$$

where b is a constant, the value of which must be found in the first instance by trial. In the present case we will suppose its value to be 2, using the same units as before—diameter measured in mils and length in inches.

To find the lengths for the above filaments a, b and c, we have

(a) $$l = 2 \times \frac{8}{4 \cdot 7} = 3 \cdot 4 \text{ in.},$$

(b) $$l = 2 \times \frac{16}{7 \cdot 4} = 4 \cdot 33 \text{ in.},$$

(c) $$l = 2 \times \frac{32}{16 \cdot 5} = 3 \cdot 88 \text{ in.}$$

The sizes of the filaments are, therefore, for

(a)	4·7	mils	diameter and	3·4in.	long,
(b)	7·4	,,	,,	4·33	,,
(c)	16·5	,,	,,	3·88	,,

in order to give the required candle-power at the volts and temperature required.

By carefully measuring the diameter and length it is thus easy to obtain lamps very closely alike.

There is, however, one trouble to be guarded against with unflashed filaments. Unless they have been carbonised at a very high temperature they are apt to fall in resistance, and will consequently run too bright. To obviate this they must be run during pumping considerably brighter than they will afterwards have to run. This can very easily be done, and it makes the filaments settle down to their permanent resistance, which is, of course, that which is calculated upon in determining the size.

Were it not for the superior lasting power of deposited carbon the process of flashing would not be resorted to at all, as lamps come out much more uniform without being flashed.

Now filaments can, of course, be of any other section than circular. Let us consider how the sizes of some other shapes can be calculated.

Square Filaments.

Suppose the filaments are square in section.

Let the side of the square $=\sigma$; then, as before, $c^2 r$ is proportional to the surface. The surface is proportional to σ;

$$\therefore c^2 r \propto \sigma$$

and $$r \propto \frac{1}{\sigma^2};$$

$$\therefore \frac{c^2}{\sigma^2} \propto \sigma,$$

or $$c \propto \sigma^{\frac{3}{2}},$$

and $$\sigma \propto c^{\frac{2}{3}},$$

or $$\sigma = a c^{\frac{2}{3}}$$

and the length $$l = b\,\frac{\text{c.p.}}{\sigma}.$$

The constants a and b have, of course, different values from those in the formulæ for circular filaments.

With filaments made of the same material,

$$a = 8{\cdot}5 \text{ and } b = 1{\cdot}575,$$

or, a for square filaments $= {\cdot}85\, a$ for circular ones,
and b ,, ,, $= {\cdot}788\, a$,, ,,

Let us find the sizes, using square filaments for the same lamps a, b, and c.

(*a*) $$\sigma = a c^{\frac{2}{3}},$$
$$= 8{\cdot}5 \times {\cdot}468,$$
$$\sigma = 4 \text{ mils},$$

and $$l = b\,\frac{\text{c.p}}{\sigma} = 1{\cdot}575 \times \frac{8}{4} = 3{\cdot}16 \text{ inches.}$$

In the same way for (*b*)

$$\sigma = 6{\cdot}32 \text{ mils},$$
$$l = 4 \text{ inches};$$

and for (*c*) $$\sigma = 14{\cdot}1 \text{ mils},$$
$$l = 3{\cdot}58 \text{ inches.}$$

Putting these results side by side, we have—

	Circular filaments.	*Square filaments.*
(*a*)	$d =$ 4·7 mils.	$\sigma =$ 4 mils.
	$l =$ 3·4 inches.	$l =$ 3·16 inches.
(*b*)	$d =$ 7·4 mils.	$\sigma =$ 6·32 mils.
	$l =$ 4·33 inches.	$l =$ 4 inches.
(*c*)	$d =$ 16·5 mils.	$\sigma =$ 14·1 mils.
	$l =$ 3·88 inches.	$l =$ 3·58 inches

The side of the square in the square filament is always 0·85 of the diameter of the corresponding circular filament.

In order to see that the above are the correct corresponding values, it is only necessary to see that the surfaces and the resistances correspond in each case.

Take the lamp (*c*).

The surface of the round filament $= \pi\, d\, l = 3{\cdot}14 \times 16{\cdot}5 \times 3{,}880 = 200{,}000$ sq. mils; the square filament $= 4\,\sigma\, l = 4 \times 14{\cdot}1 \times 3{\cdot}58 = 200{,}000$ sq. mils also.

Now, for the resistances to be equal, the ratio of $\dfrac{\text{length}}{\text{cross section}}$ must be equal in both cases, *i.e.*,

$$\frac{l}{\pi\, r^2} \text{ must } = \frac{l}{\sigma^2},$$

$$\frac{l}{\pi\, r^2} = \frac{3{\cdot}88}{3{\cdot}14\,(8{\cdot}25)^2} = 0{\cdot}018,$$

and

$$\frac{l}{\sigma^2} = \frac{3{\cdot}58}{(14{\cdot}1)^2} = 0{\cdot}018 \text{ also.}$$

Flat Filaments.

Filaments which are made from sheets of any material are often not square in section, but are wider than they are thick.

In this case there are three variables—the length, the width, and the thickness. The result is that there are any number of different dimensions which may be given to such filaments, within certain limits. Theoretically, the only limit is in the length. The greatest length is that when the section becomes a square, there being no limit to the width or thickness. In practice, however, there are, of course, limits to all these dimensions.

It may be decided to use filaments of a certain length, and to adjust the width and thickness accordingly. It is usually, however, the thickness which is fixed, and the length and width which have to be proportioned to suit. If the filaments are cut or punched from thin sheets of material, the thickness of the sheets determines what the width and length of the filaments will have to be.

First of all, let us suppose that the length is to be fixed, and it is, therefore, required to find what the width and thickness must be.

Let $t =$ the thickness of the filament,
$w =$ the width of the filament,
$h =$ the circumference of the filament,
$l =$ the length of the filament;

then
$$h = 2\,(t + w),$$
$$t = \frac{h}{2} - w,$$
and
$$w = \frac{h}{2} - t.$$

As before, the surface must be proportioned to the power or,
$$h\,l \propto c^2 r,$$
and
$$r \propto \frac{l}{t\,w};$$
$$\therefore h\,l \propto \frac{c^2 l}{t\,w},$$
or,
$$h\,t\,w \propto c^2,$$
or,
$$h\,t\,w = a\,c^2,$$
where a is a constant, as before.

Substituting $\frac{h}{2} - w$ for t, we get
$$w^2 - \frac{h}{2}\,w = -a\frac{c^2}{h},$$
or,
$$w = \frac{h}{4} \pm \frac{\sqrt{\left(\frac{h^2}{4} - \frac{4\,a\,c^2}{h}\right)}}{2};$$
for filaments of the same material as before,
$$a = 2{,}460.$$

Let us find the width and thickness for filaments for the lamps a, b, and c, as before, and let the length of each filament be 3 inches $=$ 3,000 mils.

First of all it is necessary to find h.
$$h = \frac{\text{surface of filament.}}{\text{length of filament.}}$$
Now the surface is proportional to the watts, and therefore to the candle-power, and for a given quality of carbon the surface per candle-power will always be the same. The surface per candle-power for the particular carbon of the lamps a, b, and c will be seen to be 6,300 square mils.

Consequently for lamp (a)

$$\text{surface} = 8 \times 6{,}300 = 50{,}400 \text{ square mils};$$

therefore, $$h = \frac{50400}{3000} = 16{\cdot}8 \text{ mils},$$

and we have $$w = \frac{16{\cdot}8}{4} \pm \frac{\sqrt{\left(\frac{16{\cdot}8^2}{4} - \frac{4 \times 2460 \times {\cdot}32^2}{16{\cdot}8}\right)}}{2},$$

from which we find that $w = 4{\cdot}2 \pm 1{\cdot}68$

or $$w = 5{\cdot}82 \text{ or } 2{\cdot}58 \text{ mils}.$$

Similarly for lamp (b) $w = 14{\cdot}75$ or $2{\cdot}05$ mils,

and for lamp (c) $w = 27{\cdot}6$ or 6 mils.

Of these two values given by the equation, one is the thickness and the other is the width of the filament.

Secondly, let us suppose that the thickness is fixed, and it is, therefore, necessary to find the width and the length.

We have from above $h\,t\,w = a\,c^2$

and $$h = 2\,(t + w),$$

from which we get $$w = \sqrt{\left(\frac{a\,c^2}{2\,t} + \frac{t^2}{4}\right)} - \frac{t}{2},$$

$$a = 2{,}460, \text{ as before}.$$

Having found the width, the length can be found, as in the case of circular or square filaments. We have

$$l\,(t + w) \propto \text{c.p.},$$

or $$l = b\,\frac{\text{c.p.}}{t + w},$$

$$b = 3{\cdot}15.$$

Let us find the width and length for the lamps a, b, and c as before, supposing that the thickness of the filaments is to be 3 mils.

We get for (a)	width =	5·15 mils,	length =	3·1in.
(b)	,, =	11·5 ,,	,, =	3·48in.
(c)	,, =	41·7 ,,	,, =	2·26in.

Hollow Circular Filaments.

Circular filaments are sometimes made hollow. Such filaments have been supposed to be more efficient than solid ones, because there is no power being spent in the hollow centre, the power being all used in heating the surface. This is, of

course, a fallacy. Two filaments with the same extent of radiating surface, the one solid and the other hollow, will require exactly the same amount of power to maintain them at the same temperature. If they are the same length, the only difference will be that the hollow one will have a higher resistance, and will, therefore, take a greater voltage and less current than the other, but the product of the volts and amperes (watts) will be the same for each. The effect of making filaments hollow can be best seen by finding the sizes for the lamps a, b, and c, as before.

Let $d =$ the outer diameter,

$\delta =$ the inner ,,

$d = n\,\delta$.

As before, surface $\propto c^2 r$,

or $d\,l \propto c^2 r$,

and $r \propto \dfrac{l}{d^2 - \delta^2}$;

therefore, $d\,l \propto \dfrac{c^2\,l}{d^2 - \delta^2}$,

or $d \propto \dfrac{c^2}{d^2 - \delta^2}$, or $d\,(d^2 - \delta^2) \propto c^2$.

Substituting $\frac{d}{n}$ for δ, and simplifying, we get

$$d = a\,c^{\frac{2}{3}}\left(\frac{n^2}{n^2 - 1}\right)^{\frac{1}{3}},$$

the constant a having the same value as in the formula for solid circular filaments. The formula for length (and the constant b) is the same as for solid filaments,

$$l = b\,\frac{\text{c.p.}}{d}.$$

We have then only to take the values found for circular solid filaments, and multiply by

$$\left(\frac{n^2}{n^2 - 1}\right)^{\frac{1}{3}}.$$

It is, however, more convenient in the first instance to think of a certain ratio of the diameter to the actual thickness of the wall of the filament than of the ratio of the diameter to the internal diameter.

Therefore, let $t =$ thickness of the wall of the filament, and let $m =$ the ratio of the diameter to the thickness.

Then $$d = n\,\delta = m\,t,$$

and $$t = \frac{d - \delta}{2}.$$

Consequently, $$n = \frac{m}{m - 2}.$$

Now, in the lamps a, b, and c, let the thickness of the wall of the filaments be one-tenth of the diameter.

Then $$m = 10$$

and $$n = \frac{10}{8} = 1{\cdot}25.$$

We therefore get, taking the values found for circular solid filaments, and multiplying them by $\left(\frac{n^2}{n^2 - 1}\right)^{\frac{1}{3}} = 1{\cdot}41$,

	d	δ	t	l
(a)	6·6 mils.	5·28 mils.	0·66 mils.	2·43 ~~mils.~~ inch.
(b)	10·47 ,,	8·39 ,,	1·04 ,,	3·06 ~~,,~~
(c)	23·3 ,,	18·65 ,,	2·33 ,,	2·75 ~~,,~~

We have now seen how the sizes of filaments may be obtained for the most usual forms of cross section. The results found for the lamps a, b, and c are here tabulated together. It will be found that the resistance and the surface of all the varieties for each of the lamps a, b, and c are the same in each case, and therefore the lamps will be of the same volts, amperes, and candle-power in each case.

Form of Section.		Lamp (a) 100 Volts, 8 Candles, 32 Watts.	Lamp (b) 100 Volts, 16 Candles, 64 Watts	Lamp (c) 60 Volts, 32 Candles, 128 Watts.
Circular	diameter ...(mils)	4·7	7·4	16·5
	length......(inches)	3·4	4·33	3·88
Square	side .. ..(mils)	4·0	6·32	14·1
	length......(inches)	3·16	4·0	3·58
Rectangular when length is fixed ...	length......(inches)	3·0	3·0	3·0
	thickness ...(mils)	2·58	2·05	6·0
	width.........(mils)	5·82	14·75	27·6
Rectangular when thickness is fixed	thickness ...(mils)	3·0	3·0	3·0
	width ..... (mils)	5·15	11·5	41·7
	length......(inches)	3·1	3·48	2·26
Hollow circular when $\frac{d}{t}$ is fixed...	outside diam.(mils)	6·6	10·47	23·3
	inside diam. (mils)	5·28	8 39	18·65
	length......(inches)	2·43	3·06	2·75
	thickness ... (mils)	0·66	1·04	2·33

The solid circular form gives the longest filament, the ratio of section to circumference being then greater than with any other form. The tubular form gives the next longest, and may give any length, from that of the circular solid downwards. The rectangular section gives any length, from that where the section is a square downwards.

The law that the power spent in a filament in order to maintain it at a certain temperature must be proportional to the extent of radiating surface is only strictly true when the filaments are straight, not bent into the form of a horseshoe, or other shape. That is to say, it is only true when the filament does not radiate to and from itself. With circular filaments of small diameter, bent into the horseshoe form, with a distance between the sides of perhaps a hundred times the diameter, the error is inappreciable. When, however, the diameter of the filament is much greater than a hundredth part of the distance between the two legs there may be a serious error in using these formulæ. The error will be most serious in the case of flat filaments. If a flat filament be selected, according to the formula given, and be mounted in the lamp so that the thin edges are towards each other, it will come out all right. If, however, it be mounted with its broad sides facing each other, it will run too bright.

The effect of flashing upon the sizes of the filaments will now be considered.

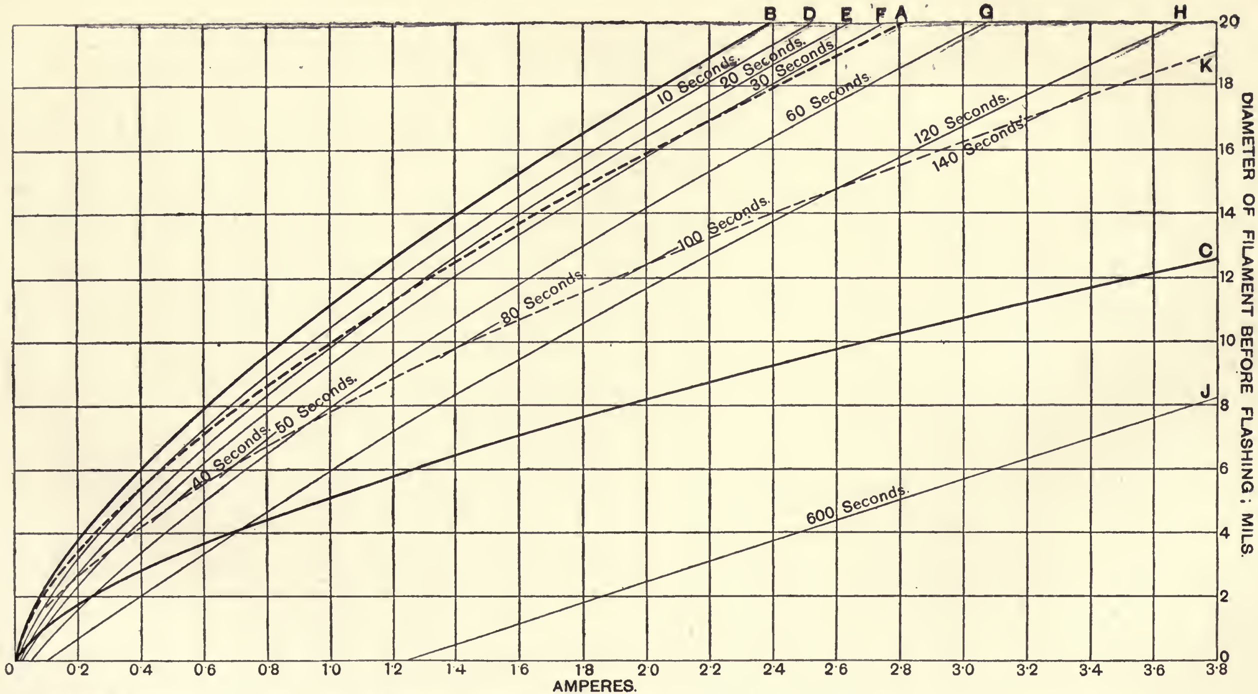
CHAPTER VII.

SIZES OF FILAMENTS (FLASHED).

THE effect of flashing is threefold, as already explained. It alters the emissivity, the resistance and the thickness of the filament. It diminishes the resistance, and, usually, the emissivity, and increases the thickness. The effect of increasing the thickness is opposite to that of diminishing the emissivity. That is to say, increase of thickness means increase of candle-power, and decrease of emissivity means decrease of candle-power. The reduction in resistance and the increase in thickness continue to proceed as long as the process is going on. The emissivity, however, is changed almost entirely within the first few seconds, after which it remains practically constant.

What the lamp-maker wants to know is what sized filament he must take in order to produce such and such a lamp. If he is making unflashed filaments the matter is very simple, and the dimensions are readily calculated, as already explained. If, on the contrary, he wishes to flash his filaments, the conditions are complicated by the three separate effects just mentioned, which we will now deal with.

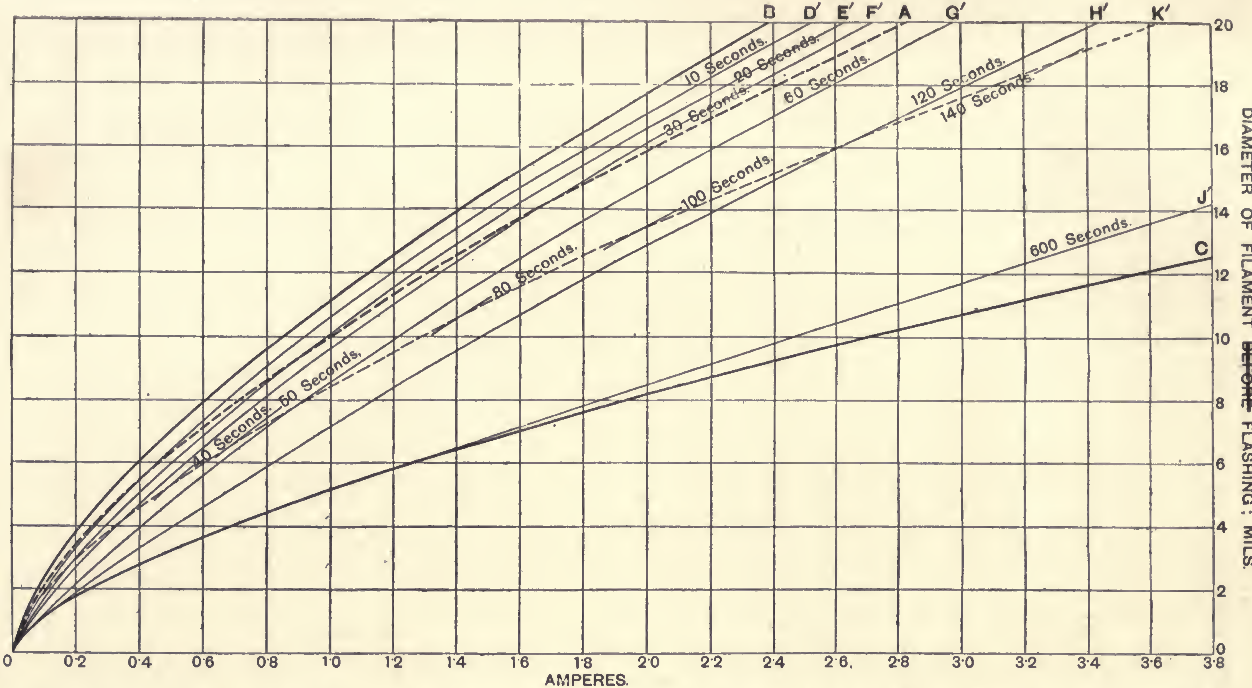
A formula for calculating diameters for flashed filaments, on the same lines as those already given for unflashed ones, might here be given. Owing, however, to the necessity for the introduction of constants, on account of the difference in specific resistance of the filaments and the deposited carbon, it becomes too cumbrous for practical use, and is, therefore, omitted. Instead of using the formula, a number of different cases can be worked out separately, and the results plotted out in curves, from which any other sizes can be easily and quickly obtained. Such curves are shown in Figs. 24 and 25.



Thickness of deposit on D=0·05 mil, and for finished diameter add 0·1 mil.	Thickness of deposit on G=0·30 mil, and for finished diameter add 0·6 mil.
,, ,, E=0·10 ,, ,, ,, ,, ,, 0·2 ,,	,, ,, H=0·60 ,, ,, ,, ,, ,, 1·2 ,,
,, ,, F=0·15 ,, ,, ,, ,, ,, 0·3 ,,	,, ,, J=3·00 ,, ,, ,, ,, ,, 6·0 ,,

Curve A gives diameters for currents up to 3 amperes for the usual quality of unflashed carbon.

FIG. 24.—Curves showing Relation between Current and Diameter of Filaments for Different Durations of the Flashing Process.
(The diameters represent the measurement of the filaments *before* being flashed.)



D′ has been flashed for 10 secs., and is 0·1 mil thicker than before flashing.	G′ has been flashed for 60 secs., and is 0·6 mil thicker than before flashing.
E′ " " " 20 " " 0·2 " " " " "	H′ " " " 120 " " 1·2 " " " " "
F′ " " " 30 " " 0·3 " " " " "	J′ " " " 600 " " 6·0 " " " " "

FIG. 25.—Curves showing Relation between Current and Diameter of Filaments for Different Durations of the Flashing Process. (The diameters represent the measurement of the filaments *after* being flashed. A, B, and C are the same curves as on Fig. 24.)

Before commenting upon the curves, the method by which they were calculated will be explained. The filaments themselves are of the same quality (*i.e.*, specific resistance and emissivity) as those of the three lamps *a*, *b*, *c*, sizes for several shapes of which have been already given. This particular quality, as already mentioned, is about the usual one obtained with filaments made from amyloid. For unflashed circular filaments it was shown (p. 71) that $d = a\,c^{\frac{2}{3}}$, and that with this carbon the value of a is 10.

In Figs. 24 and 25 the dotted curve A gives diameters for currents up to 3 amperes for this quality of unflashed carbon.

We will now suppose that filaments of this same carbon are flashed, and that the flashing be done by the pentane process. The process is arranged as to the amount of pentane vapour in the flashing chambers, the degree of exhaustion, and the temperature to which the filament is heated, so that the deposit of carbon proceeds at the rate of 0·05 mil in thickness in 10 seconds; that is to say, the diameter of the filament is increased by twice that amount, or 0·1 mil in 10 seconds. This is a convenient rate in practice, and one that can be easily obtained by most vacuum processes.

From the dimensions found for the unflashed lamps *a*, *b* and *c* in the last chapter, the specific resistance of the carbon can be calculated, For convenience, we will take the resistance of one inch length of one square mil section. From lamp *b* we see that a filament 7·4 mils in diameter and 4·33in. long has a resistance of 156 ohms; consequently, one square mil 1in. long has a resistance of 1,560 ohms.

The deposited carbon produced as described has a specific resistance of about one-tenth of that amount, or one square mil 1in. long equals 156 ohms. The emissivity of this deposited carbon is less than that of the carbon of the filament itself in the proportion of 14 to 10; that is to say, if an unflashed filament at the temperature of 4 watts per candle-power gives a light of 14 candles, a filament of exactly the same extent of surface when flashed will give only 10 candles at the same temperature.

With these data then, assuming any dimensions we like for the filament and any duration for the flashing process, we can calculate the current which it will take when flashed to main-

tain it at the required temperature (in the present case always that of 4 watts per candle-power), and we can then plot the results in curves.

For example, take the case of a filament 10 mils in diameter. We want to find what current it will take, when flashed for, say, 30 seconds, to maintain it at the temperature of 4 watts per candle-power. Suppose it be 5in. long, what is its resistance? We know that 1in. length one square mil in section of this carbon = 1,560 ohms. Therefore, we get the resistance of this filament $= \frac{1,560 \times 5}{\pi \left(\frac{10}{2}\right)^2} = 99 \cdot 3$ ohms. What candle-power will it be at the temperature of 4 watts per candle-power? We know (from the sizes on p. 71) that 6,300 square mils of surface of this carbon gives 1 c. p. at that temperature; consequently, the candle-power of this filament $= \frac{10 \times \pi \times 5,000}{6,300}$ $= 25$. Suppose now that it is flashed for 30 seconds. It will then have a coating of deposited carbon 0·15 mil thick. Its diameter will be increased by twice that amount and, therefore, will be 10·3 mils. The resistance of the deposited carbon is that of a tube 10 mils diameter inside and 10·3 mils outside and 5in. long. The sectional area $= \pi \left[(r+t)^2 - r^2 \right] = 4 \cdot 79$ square mils. The resistance of the deposited tube, then, is that of 4·79 square mils 5in. long, and is therefore 163 ohms (one square mil 1in. long = 156 ohms).

The flashed filament is therefore made up of the filament proper of 99·3 ohms, over which is a tube of flashed carbon of 163 ohms. The resultant resistance of the filament is consequently 61·7 ohms.

Now the candle-power of the filament before flashing would have been 25, but by flashing its emissivity is reduced in the ratio of 14 to 10. But it has also been thickened in the ratio of 103 to 100

Therefore its candle-power will now be

$$25 \times \frac{10}{14} \times \frac{103}{100} = 18 \cdot 4,$$

and the power required will be $18 \cdot 4 \times 4 = 73 \cdot 6$ watts.

Now $$c^2 = \frac{w}{r} = \frac{73 \cdot 6}{61 \cdot 7} = 1 \cdot 193\,;$$

therefore, $$c = 1 \cdot 092 \text{ amperes.}$$

Thus a 10-mil filament flashed for 30 seconds takes a current of 1·092 amperes, and the filament becomes 10·3 mils diameter. The same result is, of course, arrived at whatever the length of the filament is assumed to be, the length, as previously explained, having nothing to do with the current strength.

By working out a number of cases in this way, curves such as those in Figs. 24 and 25 can be drawn.

Having obtained the curves, they are useful in enabling us to do the reverse process at a glance. For instance, a particular lamp is to be made, and its current must be so-and-so. The curves show at once what diameters of filament may be taken, and how much they must be flashed in order to produce the result.

If it is desired to give the filaments a definite thickness of deposit, there is one diameter alone which will answer the purpose. Suppose that it is desired to give a coating 0·3 mil thick. It takes 60 seconds to do this. Take the case of lamp *b*, a 100-volt 16-c.p. 0·64-ampere lamp. We find on the 60 seconds curve (Fig. 24) that we must take a filament 5·3 mils diameter to give this current. During the process of flashing it will become thickened to 5·9 mils, a fact which must be remembered in estimating its length. The length to be taken is given as before by the formula $l = b\,\frac{\text{c.p.}}{d}$, d being the finished diameter, the value of b in the case of the flashed surface being 2·8 (*i.e.*, the constant for the unflashed surface multiplied by 14/10, the ratio of the emissivities);

therefore $$l = 2{\cdot}8 \times \frac{16}{5{\cdot}9} = 7{\cdot}6\text{in.}$$

7·6in. of 5·3 mils diameter filament must then be flashed for 60 seconds, and it will then be of the right resistance and surface.

This, therefore, shows another way by which filaments may be flashed to the required resistance. No instruments are needed except a watch to show the time of flashing. Start with the proper size of filament shown by the curve, and flash it for the required length of time, and it is brought to the required resistance. Such a method, however, would not work well in practice owing to the difficulty of exactly reproducing to conditions each time. If, however, the right size of

filaments, as shown by the curve, are taken and flashed to their proper resistance hot, the time of flashing will be 60 seconds on the average.

It will be seen by examining the curves that there is a wide range of possible sizes for the filament, according to the amount of flashing it receives. For the same lamp taking 0·64 ampere, a filament 3·7 mils in diameter flashed for two minutes gives the required result, or one of 7·65 mils flashed for only ten seconds will do equally well.

It has, however, been pointed out in practice that 30 seconds is about as long a time as can be allowed for flashing. By taking the sizes given by the 30-seconds curve we get always, for any current, the diameter which will take 30 seconds to flash to its required resistance.

On examining the curves, one thing that immediately attracts attention is that the curves for the flashed filaments D, E, F, G, H, J, cross the curve for the unflashed ones A, at some point. This is on account of the variation in the equivalent specific resistance of the flashed filaments.

The topmost heavy curve B shows what the result would be if the filaments could be flashed so as to give the less emissivity of the deposited carbon, but without changing the resistance. In other words, it is the curve for a carbon of the specific resistance of the unflashed, but with the emissivity of the deposited variety. It is introduced in order to show the limit of diameter for any current beyond which it is impossible to go under any conditions with these two qualities of carbon. In the other direction the limit of the diameter is zero; that is to say, the amyloid filament vanishes altogether, deposited carbon alone remaining.

Thus the diameter selected for a 1·25-ampere filament at the temperature of 4 watts per candle-power may be anything from 12·9 mils down to nothing, according to the time of flashing. If unflashed carbon is used, the diameter, as shown by the dotted curve A, will be 11·6 mils; if flashed for 10 seconds, it will be 12·3 mils; for 20 seconds, 11·7 mils; for 30 seconds, 11·15 mils; for one minute, 9·7 mils; for two minutes, 7·5 mils. The limit of zero diameter is reached (supposing such a thing possible) at the ten-minutes curve. It must be remembered that the diameters shown by the curves on Fig. 24

are the diameters of the filaments before flashing, and that the actual finished diameters are greater according to the length of time they are flashed by one-tenth of a mil for every 10 seconds. In the limit when the diameter of the unflashed carbon becomes zero the actual diameter is $0+6$ mils, 6 mils being the increase in diameter produced in ten minutes. In other words, the filament is now entirely of deposited carbon, and 6 mils in diameter. Speaking, then, of the final or flashed diameter, the limits for 1·25 amperes are 12·9 mils and 6 mils, 6 mils being the diameter of a solid filament of deposited carbon alone. The lower heavy curve C gives the values for such material. It of course follows the $d=a\,c^{\frac{2}{3}}$ law, the value of the constant a being 5·17.*

In order to make the matter as clear as possible the second sheet of curves (Fig. 25) is given, showing the final or flashed diameters. It will be noticed that all the sizes lie between the limits of the heavy curves B and C. It is, however, the diameters of the filaments before flashing that the lamp-maker requires in the first instance.

Looking at the curves (Fig. 25) we see for any current within what limits the final diameter of the filament for that current must lie. Thus, for two amperes the final diameter will lie between 8·2 and 17·7 mils. Theoretically, any diameter between these limits may be made to do for two amperes, according to the length of time of flashing, or no

* The value of the constant may be found by taking any particular case and working it out, thus

$$d=a\,c^{\frac{2}{3}} \;\therefore\; a=\frac{d}{c^{\frac{2}{3}}}.$$

Suppose the filament of a solid deposited carbon to be 5in. long and 10 mils diameter, its sectional area $=78{\cdot}54$ square mils and its resistance, therefore, is

$$\frac{156\times5}{78{\cdot}54}=9{\cdot}93 \text{ ohms.}$$

Its surface $=157{,}000$ sq. mils.

The surface per candle-power of the deposited carbon

$$=6{,}300\times\frac{14}{10}=8{,}820 \text{ sq. mils;}$$

therefore its candle-power $=\dfrac{157{,}000}{8{,}820}=17{\cdot}8$, and the watts $=17{\cdot}8\times4=71{\cdot}2$

therefore $$c^2=\frac{W}{R}=\frac{71{\cdot}2}{9{\cdot}93}=7{\cdot}17,$$

and $$c^{\frac{2}{3}}=1{\cdot}93;$$

consequently $$a=\frac{10}{1{\cdot}93}=5{\cdot}17.$$

flashing at all if the filament be 15·9 mils, as shown by the dotted curve A.

In actual practice the limits are somewhat more restricted, on account of the difficulty of making or handling very thin filaments or of flashing properly in less than 10 seconds. The practical limits for this current may, however, be considered as 10 mils and 17 mils finished diameter, still a very wide range, according as to whether the flashing be done for 10 seconds or up to five or six minutes. This means that the filament before flashing will have a range of from 4 or 5 mils to 17 mils in diameter. If the time of flashing is to be restricted to 30 seconds, then 16·05 mils will be the finished diameter and 15·75 the diameter before flashing.

The fact that flashing a filament may *reduce* as well as increase the current strength necessary to raise it to a given temperature is one which the Author believes to be not generally realised. Looking at the curves for finished diameters, it is seen that an unflashed filament of 14 mils diameter takes about 1·66 amperes. A filament of this diameter which has been flashed for 10 seconds takes only 1·49 ampere. One which has been flashed for 20 seconds takes 1·58 ampere, while one flashed for 30 seconds takes 1·66 ampere, the same as the unflashed filament of that diameter. If flashed for a longer time than 30 seconds, it takes more current than the unflashed one.

When the diameter and current are the same for unflashed and flashed, as in this case for fourteen mils and thirty seconds, the lengths of the filament to produce the same volts and candle-power will be in the proportion of ten to fourteen, the length of the flashed filament being greater in inverse proportion to the alteration in emissivity.

Looking at the curves showing the diameters *before* flashing we see that an unflashed filament of 16·8 mils diameter takes 2·18 amperes. If this same filament be flashed for 10 seconds, it takes only 1·97 ampere, if it be flashed for 20 seconds it takes 2·07 amperes, and if for 30 seconds it takes 2·18 amperes, the same as it did before being flashed. Its diameter is, of course, increased by 0·3 mil, and is thus 17·1 mils.

Here, again, let there be no misunderstanding about efficiency. The filament which is flashed for a short time and

which takes less current and fewer volts than it did before flashing to maintain it at a certain temperature, is no more efficient than before flashing. The power required to produce the temperature is less. In precisely the same proportion is the candle-power also less.

When filaments are flashed to a certain resistance measured cold, it has already been pointed out, that owing to the widely different temperature coefficients of the filament and the deposited carbon, it is essential that the ratio of the two amounts of these carbons present in the filament be known. In a factory where the cold measurement is adopted it should be a rule always to flash the filaments so that there is a fixed ratio between the sectional area of the filament and that of the deposit, that is to say, between their resistances.

It has been mentioned that the general formula for diameters of flashed filaments is too cumbrous for ordinary use, owing to the difference in the specific resistance of the two kinds of carbon having to be taken into consideration. When, however, there is a fixed ratio between the quantities of the two kinds of carbon in the filament, the formula becomes again of the simple form, $d = a\, c^{\frac{2}{3}}$; because in such a case we may consider the flashed filaments as having a definite specific resistance. In order, then, to find the right diameters to use, so that there shall always be a fixed ratio between the resistance hot and the resistance cold, it is only necessary to find the value of the constant a for whatever ratio is required, and the formula gives the required result. With the same qualities of filament and deposited carbon, then, let us find the value of a, so that the cold resistance may be for all diameters equal to twice the hot resistance.

It has been mentioned (p. 62) that the ratio of the cold resistance to the hot in the case of the filaments is as 1·5 to 1, and in the case of the deposited carbon as 2·5 to 1. We want to combine them in such a proportion that the ratio shall be as 2 to 1.

With these ratios, if the filament be 100 ohms hot, the deposit must be 60 ohms hot. The resultant resistance hot will then be

$$\frac{100 \times 60}{160} = 37{\cdot}5 \text{ ohms.}$$

The cold resistance of the filament will be $100 \times 1{\cdot}5 = 150$ ohms, and that of the deposit will be $60 \times 2{\cdot}5 = 150$ ohms. The combined resistance cold will therefore be 75 ohms,

$$2 \times 37{\cdot}5 = 75.$$

In order, then, for the resistance cold to be twice the hot resistance, the hot resistance of the deposit must equal 0·6 of the hot resistance of the filament.

Now the specific resistance of the filament is ten times that of the deposited carbon. Consequently, the sectional area of the filament must be $10 \times 0{\cdot}6 = 6$ times that of the deposit.

Let $r =$ radius of the filament,
$t =$ thickness of the deposit,
section of filament $= \pi r^2$,
section of deposit $= \pi \left[(r+t)^2 - r^2 \right]$;
therefore $6\pi \left[(r+t)^2 - r^2 \right] = \pi r^2$;
from which we get $t = 0{\cdot}081r$, or $r = 12{\cdot}37t$;
$t = 0{\cdot}0405d$, or $d = 24{\cdot}74t$,
where $d = 2r$; or, if D = the finished diameter, $t = 0{\cdot}0374\,\text{D}$.

With flashing at the same rate as before, *i.e.*, 0·05 mil thickness of deposit in ten seconds, it follows that for every mil in diameter the filament must be flashed for 8·1 seconds to produce the required ratio.

As before $d = a\,c^{\frac{2}{3}}$, and therefore $a = \dfrac{d}{c^{\frac{2}{3}}}$. In order to find a, take any filament and find $c^{\frac{2}{3}}$. Let the filament be 10 mils in diameter, and t will be 0·405 mil. For convenience of having round numbers in the resistance let the length be 5·05in. The sectional area of the filament equals 78·54 square mils, and the resistance, therefore, is

$$\frac{1{,}560 \times 5{\cdot}05}{78{\cdot}54} = 100 \text{ ohms}.$$

The sectional area of the deposit $= \pi\,(5{\cdot}405^2 - 5^2) = 13{\cdot}1$ square mils. And the resistance of the deposit

$$= \frac{156 \times 5{\cdot}05}{13{\cdot}1} = 60 \text{ ohms}.$$

The resultant resistance, as we have already seen, is therefore

$$\frac{100 \times 60}{160} = 37{\cdot}5 \text{ ohms}.$$

Now, the surface of the filament = length × circumference = 5,050 × 10·81 × π = 171,500 square mils. One candle-power of this flashed surface = $6{,}300 \times \frac{14}{10} = 8{,}820$ square mils; consequently the candle-power of this filament

$$= \frac{171{,}500}{8{,}820} = 19{\cdot}5.$$

And the power $= 19{\cdot}5 \times 4 = 78$ watts,

$$c^2 = \frac{w}{r} = \frac{78}{37{\cdot}5} = 2{\cdot}08;$$

therefore $c = 1{\cdot}44$ ampere,

and $c^{\frac{2}{3}} = 1{\cdot}27$,

and $a = \frac{10}{1{\cdot}27} = 7{\cdot}85$;

or for finished diameter $a = \frac{10{\cdot}81}{1{\cdot}27} = 8{\cdot}46$.

The curves K and K′ (Figs. 24 and 25) give the diameters before and after flashing.

Supposing, then, that the filaments are flashed until the resistance measured cold is brought down to the value of twice the required resistance hot, we can at once find the diameter for any current from these curves, and we can also see the time which will be occupied in the flashing by the crossing of the curve with the time curves D, E, F, G, &c.

For example, suppose we are flashing to cold resistance and wish to make lamp *b* (p. 78) 100 volts 16 c.p. 0·64 ampere. Looking at the curves K and K′, we see that for this current the diameter before flashing is 5·8 mils, and after flashing is 6·3 mils. The length required will be given, as before, by the formula,

$$l = b\frac{\text{c.p.}}{d} = 2{\cdot}8 \times \frac{16}{6{\cdot}3} = 7{\cdot}1\text{in.}$$

The resistance hot $= \frac{e}{c} = \frac{100}{0{\cdot}64} = 156{\cdot}25$ ohms.

Consequently, the cold resistance must be $2 \times 156{\cdot}25 = 312{\cdot}5$ ohms. If, therefore, we take a filament 5·8 mils thick and 7·1in. long, and flash it to 312·5 ohms cold, we get what we require.

The values taken from the curves are as near as can possibly be required in practice, but if it is wished to know the figures

more closely, we can use the formula

$$d = ac^{\frac{2}{3}},\ a = 8{\cdot}46,$$

from which $d = 6{\cdot}284$ mils.

Let us see if these values work out correctly. The final diameter is equal to the diameter before flashing + twice the thickness of the deposit, and (p. 91) we know that the diameter before flashing must = 24·74 times the thickness of the deposit; consequently, the diameter before flashing

$$= \frac{24{\cdot}74}{26{\cdot}74} \times 6{\cdot}284 = 5{\cdot}82 \text{ mils.}$$

The section of the filament $= \pi r^2 = 26{\cdot}585$ square mils.
1 square mil 1in. long $= 1{,}560$ ohms;

$\therefore$ 26·585 mil 7·1 long $= \dfrac{1{,}560 \times 7{\cdot}1}{26{\cdot}585}$,

or the resistance of the filament = 416·6 ohms.

The section of the deposit $= \pi[(r+t)^2 - r^2]$
$= 4{\cdot}431$ square mils.
1 square mil, 1in. long $= 156$ ohms;

$\therefore$ 4·431 mil 7·1 long $= \dfrac{156 \times 7{\cdot}1}{4{\cdot}431}$,

or the resistance of the deposit = 250 ohms,

and the combined resistance $= \dfrac{416{\cdot}6 \times 250}{416{\cdot}6 + 250} = 156{\cdot}25$ ohms.

Let us now find the candle-power. The surface $= \pi \times 6{\cdot}284 \times 7{,}100 = 140{,}200$ square mils. Therefore the candle-power

$$= \frac{140{,}200}{8{,}820} = 16.$$

The volts, amperes and candle-power are therefore correct.

Lastly, let us see if the resistance cold is twice the resistance hot.

The resistance of the filament hot = 416·6 ohms, therefore, cold, it is $416{\cdot}6 \times 1{\cdot}5 = 625$ ohms.

The resistance of the deposit hot = 250 ohms, therefore, cold, it is $250 \times 2{\cdot}5 = 625$ ohms.

The combined resistance cold, therefore, is

$$\frac{625 \times 625}{625 + 625} = 312{\cdot}5,$$

which is twice the hot resistance, hence the filament fulfils all the conditions required of it.

Filaments of any diameter flashed for less time than that indicated by the curve K, will have a ratio of cold to hot resistance of less than 2, and if flashed for a longer time will have a greater ratio.

Instead of finding the value for the constant a, in the formula $d = a\,c^{\frac{2}{3}}$ by the method of working out a particular example, we will proceed to consider how its value may be found for any case where the current and diameter follow this law.

The constant a is really made up of two other constants, which we will call α and β. We have seen that

$$c^2\,r \propto d, \text{ and that } r \propto \frac{1}{d^2}.$$

Let $\quad c^2\,r = \alpha\,d$ for unit length of filament,

and let $\quad r = \frac{\beta}{d^2}$ for ,, ,,

then $\quad c^2 \times \frac{\beta}{d^2} = \alpha\,d,$

or $\quad c^2 = \frac{\alpha}{\beta} d^3$ and $d^3 = \frac{\beta}{\alpha}\,c^2,$

or $\quad d = \left(\frac{\beta}{\alpha}\right)^{\frac{1}{3}} \times c^{\frac{2}{3}};$

consequently, the constant $a = \left(\frac{\beta}{\alpha}\right)^{\frac{1}{3}}.$

Taking the unflashed carbon as the starting point, let us find the values for α and β. Take the case of a filament 10 mils in diameter and 1in. long.

The surface $= 10 \times \pi \times 1{,}000 = 31{,}416$ square mils. We know that 6,300 square mils $= 1$ c.p.

Therefore the candle-power $= \frac{31{,}416}{6{,}300} = 5,$

and the power $\quad = 5 \times 4 = 20$ watts.

$$\alpha = \frac{c^2\,r}{d} = \frac{20}{10} = 2.$$

The sectional area of the filament $= \pi\,r^2 = 78{\cdot}54$ square mils. We know that one square mil 1in. long $= 1{,}560$ ohms; therefore the resistance $= \frac{1{,}560}{78{\cdot}54} = 20$ ohms.

$$\beta = d^2\,r = 2{,}000,$$

and therefore $$a = \sqrt[3]{\frac{\beta}{\alpha}} = \sqrt[3]{\frac{2{,}000}{2}} = 10,$$

which is the value assigned to a at the first (p. 71).

We are now able to find the value of the constant a for any carbon, if we know its relative specific resistance and emissivity to that of this carbon.

Let us find its value by this method for the same carbon flashed so that its cold resistance shall be equal to twice its hot resistance.

We know that by being flashed its emissivity will be reduced in the proportion of 14 to 10; consequently,

$$\alpha = 2 \times \frac{10}{14} = 1{\cdot}43.$$

As in this case there is always a fixed ratio between the sectional area of the deposit and that of the filament, we can find its equivalent specific resistance.

It has been shown that the resistance of the deposit must be 0·6 times that of the filament. If, therefore, the resistance of the filament be 100 ohms, that of the deposit will be 60 ohms, and the combined resistance will be 37·5 ohms. But in being flashed the diameter of the filament is increased in the ratio of $\frac{13{\cdot}37}{12{\cdot}37}$ (p. 91).

Consequently, the resistance of an unflashed filament of the same diameter and length as the flashed one will be $100 \times \left(\frac{12{\cdot}37}{13{\cdot}37}\right)^2 = 85{\cdot}6$ ohms. Therefore the equivalent specific conductivity has been increased by flashing in the ratio of

$$\frac{85{\cdot}6}{37{\cdot}5} = 2{\cdot}28\,;$$

consequently, $$\beta = 2{,}000 \times \frac{1}{2{\cdot}28} = 876\,;$$

therefore, $$a = \sqrt[3]{\frac{\beta}{\alpha}} = \sqrt[3]{\frac{876}{1{\cdot}43}} = 8{\cdot}46,$$

which is the value found on page 92.

In the same way, by first finding the values for α and β, the value of a can be found for any quality of carbon, or for flashed carbon which has a definite ratio between the sectional area of the filament and that of the deposit.

The following values for a, for filaments flashed so as to have a definite ratio between their cold and hot resistance, have been calculated in the same way.

$\dfrac{\text{Cold resistance.}}{\text{Hot resistance.}}$	$\dfrac{\text{Conductivity of flashed filament (hot).}}{\text{Conductivity of filament of equal diameter not flashed (hot).}}$	α	β	a
1·6	1·167	1·43	1715	10·62
1·7	1·362	1·43	1469	10·09
1·8	1·6	1·43	1250	9·52
1·9	1·9	1·43	1053	9·02
2·0	2·28	1·43	876	8·46
2·1	2·83	1·43	707	7·91
2·2	3·52	1·43	568	7·35
2·3	4·62	1·43	433	6·72
2·4	6·44	1·43	311	6·01

Curves for current and diameter for flashed filaments having these ratios of cold to hot resistance might be plotted on Fig. 25 along with the "time of flashing" curves D, E, F, &c., which they would cross. To save confusion one only (curve K′) has been drawn.

In many lamp factories, the sizes of filaments and the amount of flashing they receive are regulated entirely by guess and trial methods. Such methods, no doubt, answer the purpose in the end just as well as a calculation by a formula, or information obtained from a curve. But by a proper understanding of the effects produced by alterations in the diameter of the filament or the time or conditions of the flashing, the required results can be much more certainly and quickly obtained. Of course, it is impossible to get lamps all *exactly* right by any method. There are too many causes at work to upset the calculations, too many variable conditions to be simultaneously taken into account. Nine out of ten of the things to be considered may be right, the tenth one being wrong throws the combined result wrong. It is, however, only by taking everything into consideration that good results can be expected.

The curves and the constants given for use with the various formulæ have *about* the values to be met with in ordinary practice. Carbons produced by different factories using very similar processes will, however, differ so much that it is not

possible to give any values which will be generally applicable. The exact values of the constants must, therefore, be found for each particular make of carbon and process of flashing.

A good instance of the happy-go-lucky methods sometimes used in a factory was seen by the Author a few years ago. The filaments were here flashed in an apparatus, using an automatic cut-off, which stopped the current when it attained a certain value. This cut-out was a very crude affair, and was not at all particular as to when it went off. The flashing globes were allowed to get so black that the operator could not possibly gauge the temperature of the filament, and the consequence was that the cut-off would "act" just when the operator chose to turn the current up sufficiently. After this process the filaments were "selected" by measuring their resistance cold, a range of about twenty per cent. being allowed. The result was that three-fourths of the filaments were rejected. Of those coming within the limits of the resistance cold, perhaps one-third would be of the right resistance hot, which was always assumed to be half the cold resistance. The proportion of lamps of the proper voltage was, of course, extremely small, while the percentage of filaments which became lamps of the right voltage was microscopical.

The factory above alluded to was, luckily, situated in a country where very badly-matched lamps could be sold as of the same voltage. It will be evident to the reader that the extreme care required in the production of *uniform* and good lamps necessarily adds to their cost. Lamps made without such care can be produced at a correspondingly lower rate. If the proper amount of care is taken during the manufacture, nearly all the lamps, when finished, will be close enough to the proper voltage and candle-power for them to be properly sold as such. When, however, such care is not maintained, the resulting lamps will, inevitably, be un-uniform, only a small percentage, possibly, being within the proper limits of voltage and candle-power.

With the expiration of the lamp monopoly in this country, it is to be feared that the market will be deluged with inferior and badly matched lamps, which will be offered at a very low price. Consumers will, however, probably find that the higher priced lamps are the best and, in the long run, the cheapest.

CHAPTER VIII.

MEASURING THE FILAMENTS.

The filaments must, of course, be measured before mounting and flashing, and it is well to measure them again after flashing, to see that the increase in thickness is of the proper amount. The measurement may be done in several ways—by means of micrometer gauges, or by throwing a magnified image of the filament upon a screen by means of a lamp and lens, or by the ordinary microscope method, which, however,

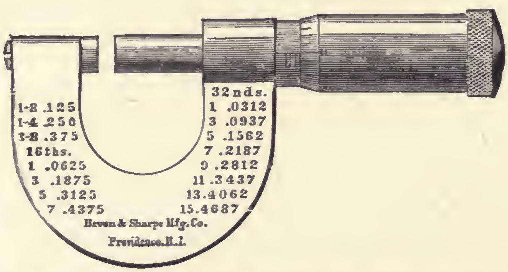


Fig. 26.—Micrometer Gauge, for Measuring Diameter of Filaments.

cannot be considered a factory method. Measuring with a micrometer can only be done with accuracy after a considerable amount of practice. The best form of micrometer to use is that represented in Fig. 26, which can be read to the fifth part of a mil. It should be mounted on a support fixed to the table, so as to be about 3in. above the table, and so that the screw head can be turned easily with the thumb and fore-finger of the right hand, with the fore-arm resting comfortably on the table. The filament will be held very lightly

between the thumb and fore-finger, or between the first and second fingers of the left hand. Great delicacy of touch is required, as the filament may be squeezed to a considerable extent, and the measurement will then be wrong. Some micrometers have a ratchet-head, so that they may be screwed up until the object to be measured is held just so tightly that the ratchet head slides round without closing the gauge any further. This arrangement is, however, not sufficiently delicate for filaments. They may be squeezed much too tightly before the ratchet comes into play. Of course a ratchet-head might easily be made to work with a very slight pressure, but the difficulty is to get one which will turn the micrometer screw without anything in the jaws (a considerable force being required to do this), and yet which will slip on the slightest extra resistance. A micrometer without the ratchet-head may be used, and it can be screwed up until it is felt that the fila-

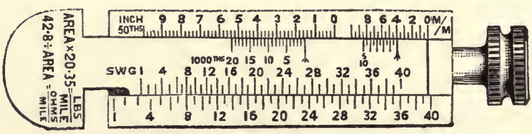


Fig. 27.—Trotter's Micrometer Gauge.

ment is being touched; but it is difficult always to squeeze to the same extent. A much more accurate plan is to slowly move the filament backwards and forwards in the direction of its length between the jaws of the micrometer, which are steadily and slowly being screwed up with the other hand. Immediately the filament is gripped, no matter how lightly, it will be felt by the fingers holding it—before the fingers of the other hand turning the micrometer feel the resistance at all. Filaments can in this way be measured very accurately. When the filaments are not properly circular there is sometimes a difficulty in getting the greatest measurement, as the micrometer tends to turn the filament round so that it measures always its least diameter.

Another instrument which can be used in the same way, is the "Trotter" wire-gauge, the screw pattern (Fig. 27). It is not, however, intended for measuring so fragile a thing as a filament, and is not so convenient as the ordinary micrometer,

as it indicates on a vernier which is so small as to require a magnifying glass to read it. It has, however, this advantage, that the jaws come together without the turning motion of the ordinary micrometer.

Fig. 28 represents another gauge which may be used. It is simply a metal plate with a V-shaped slit in it, into which the filament can be passed as far as it will go. The sides of the V are marked off in mils, so that the point at which the filament is arrested shows its thickness. The metal plate, preferably of

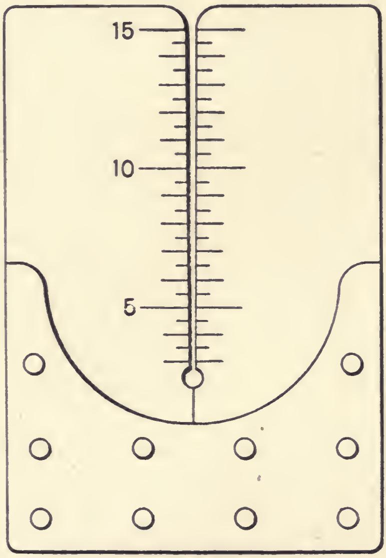


FIG. 28.—V-slot Micrometer Gauge.

steel, should not be less than a tenth of an inch in thickness. Owing to the angle between the sides of the V being so very small, there is a danger of getting the filaments down a little too far, and getting them stuck so tightly that they cannot be got out without breaking. With practice, however, this instrument can be used successfully.

The method of projecting a magnified image of the filament, or a part of it, upon a screen is very accurate if properly carried out, but, if the measurements are to be made as quickly as with the screw micrometer, it requires two persons to work it:

one to put the filaments in position, and the other to read the result on the screen. The larger the image the more accurately can it be measured on the screen. There are, however, two difficulties in making a large image. Either a very short focus lens must be used, in which case a slight error in the position of the filament will make a considerable error in the size of the image, or, if a long focus lens is used, the distance from the lens to the screen will be too great. In any case, an achromatic lens should be used, or the image of the filament will be blurred, on one side in red and on the other in blue.

If the filament is magnified one hundred diameters, the screen may be divided in tenths of an inch, in which case each division will represent one mil in the filament. The screen may be made to slide either in a vertical or horizontal direction, according as to which way the filament is held, so that the zero line of the scale may be brought to the edge of the image of the filament. Another method is to use a scale drawn on glass, the image of which is thrown together with that of the filament on to the screen. There is a slight error here, as the scale must, of course, be either in front or behind the filament, and will, consequently, be either a little too large or too small. This error will be unimportant if the lens be 1in. or more in focal length, though the image of the scale may not be quite sharp. If the lens has a focal distance of 1in., the distance of the screen from the centre of the lens will be 8ft., 5in., while the filament will be 1·01in. from the centre of the lens. This is rather inconveniently close for the handling of the filaments, but a greater focal length of lens requires a correspondingly greater distance to the screen. A lens of 3in. focal length gives more room, but the distance of the screen will then be over 25ft. A powerful illumination is required in order that the image on the screen may be easily distinguishable. An incandescent lamp similar to those made for lantern purposes answers very well, the light being concentrated on the filament by a condensing lens in the usual way. This method is very useful in determining the diameter of a filament after it has been made into a lamp, the filament itself being rendered incandescent. The filament is placed in the right position by getting it in line between two fixed wires or narrow slits in metal plates on either side.

CHAPTER IX.

GLASS MAKING.

As large lamp factories frequently make their own glass, a short description of some of the leading features of the manufacture may be of interest.

The glass used in making lamps is not just any kind of glass, but, on the contrary, is a very special kind of good glass. This is necessary, owing to its having to unite properly with platinum. The glass used is known as flint glass. It contains a large quantity of lead, and is, consequently, much heavier than glass without lead. All the materials used in its manufacture must be of very good quality. The utmost care is required in making up the mixture, as a slight deviation from the proper proportions of the ingredients may spoil a whole potful of glass.

The mixture for flint glass is, approximately, three parts by weight of pure white sand, two parts of red lead, and one part of pearlash (carbonate of potash), with small proportions of nitre, arsenic, and oxide of manganese. These ingredients are thoroughly mixed together and passed through a very fine sieve.

Experimenting in glass-making is a very expensive amusement, and the result is that the exact recipe for making any particular glass is usually difficult to obtain. The man who knows (the "mixer" as he is called) is very particular to do his mixing in strict privacy. He may, perhaps, have a boy to help him weigh out the three main ingredients, but no one may see him do the rest. The Author knew a mixer who went so far as to keep a ferocious bull-dog in the mixing-room, presumably to prevent any one from interrogating the scales in his absence. At a well-known art glass-works it is said that the owner alone knows the mixtures of the glasses, and makes

them up himself. Let the lamp maker, therefore, beware of placing himself at the mercy of a single mixer who may fall ill or be otherwise incapacitated, and thereby stop the whole works. Fortunately the *secrets* of mixtures suitable for incandescent lamp glass are widely known, and thus the only difficulty is to find a mixer who can be relied upon to be sufficiently careful in doing his work.

Every batch of glass should be carefully tested by completing a dozen lamps or so from it before the rest of the bulbs are allowed to be used. The glass may appear to be all right, but after the lamps have been made a few days, it may be found to crack at the platinums. All the bulbs made from each batch of mixture should, therefore, be kept apart until it

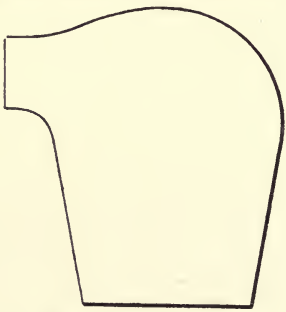


Fig. 29.—Glass Crucible for "Cone" Furnace.

is known that the glass is good. Nothing is more troublesome and costly than to get bad glass into the factory and made into lamps before the fault is discovered.

The glass furnace is usually in the form of a cone, and it generally contains six or eight pots or crucibles of the form shown in Fig. 29. These crucibles are made of fire-clay, and are entirely closed in over the top. The opening through which the glass is worked is at the side near the top, and is surrounded by a kind of hood which sticks out some inches from the pot. This is in order that the gases from the fire may not come into contact with the glass in the pot or as it is being withdrawn, as the lead would then get reduced and blacken the glass. The pots are arranged round the circular bed of the furnace with their backs inwards, and are so built in that their mouths only are visible from the outside. The

fire is in the centre and below the pots. The heated gases from the fire come up in the centre and strike the dome-shaped crown of the furnace and are deflected towards the pots, and then pass out through flues between the pots into the chimney above the crown. There are various devices for feeding the fire from below so as not to let in a rush of cold air at the same time. There are many designs of furnace, to some of which the Siemens regenerative system is applied. For fuller descriptions of furnaces, works on glass making should be consulted.

In a factory where the large output of a cone is not required, a smaller furnace may be constructed to accommodate three or four small pots like that shown in Fig. 30. These pots, having their opening in the top, are set in the furnace at an

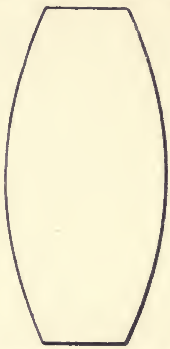


Fig. 30.—Glass Crucible for Small Furnace.

angle of about thirty degrees with the horizontal, and the front of the furnace is bricked up so that the mouths of the pots alone are seen from the front. The firing is done from behind.

Great attention has to be paid to the firing of a glass furnace in order to keep the temperature constantly at the right point. If the temperature is either too high or too low, the glass cannot be worked. Moreover, a variation in the temperature is dangerous to the pots, which will crack on the slightest provocation. There is something very mysterious about the behaviour of the crucibles in a glass-furnace. Sometimes they will last for months, or they may break in a few hours. Large glass-works make their own crucibles, but they can be bought ready-made. Spare pots should always be on hand, as they take a long time to make, or rather a long time must elapse after

making before they can be used, as they must stand to dry and harden. A glass furnace can never be allowed to go out, unless it is for extensive repairs. All the pots are lost if the temperature is lowered much. When a pot cracks and has to be replaced, the new one is slowly heated in a separate furnace, and then transferred to its position in the glass furnace. This is a somewhat difficult operation owing to the great heat. Before a new pot is charged with a glass mixture it must be glazed inside with glass from another pot. The glass mixture, together with scraps of glass, can then be poured in. It will take twenty-four hours or more before the glass is ready to be worked. Besides the trouble of the pots being liable to crack at any moment without notice, there is another danger to which they are exposed. The glass mixture will sometimes act upon the material of the pot and make holes in it, which may eventually go right through and let the molten glass out into the furnace. The pots are sometimes literally honeycombed in this way, though, of course, as soon as one hole is through, the pot is useless for further work. This is a most troublesome accident, and one against which it is difficult to guard with certainty.

As the furnace must be kept up continuously night and day, it is best to work the glass all the time so as to get the full money's worth out of the fuel. The plan in some glass-works is to charge the pots on Saturday; the glass will then be ready for working on Monday morning, from which time it will be worked continuously night and day until the following Saturday, when the pots will be again filled up.

A lamp bulb is one of the very simplest things which a glass worker can have to make. Everything which is made direct from the glass pot is, in fact, made first of all into a bulb in some form or other. Pressed glass is, perhaps, the only exception, as it is merely a lump of glass dropped into a mould and pressed. This, however, does not mean that there is no skill required in the making of a lamp bulb. The method of working is as follows: The glass worker has an iron tube some five or six feet long. He dips the end of it, after first heating it, into the molten glass and "gathers" some glass on the end. There is considerable skill required in gathering the right amount. He then withdraws the tube,

and holding it out in a somewhat inclined position, the end with the glass upon it being higher than the near end, he blows through the tube, at the same time turning it round and round, and in this way forms the glass into a hollow bulb. If he wants the bulb to assume a long or pear shape, he whirls the tube round and round as one may twirl a walking cane. It requires much skill to produce bulbs of the same size and shape in this manner, but good glass workers are able to make surprisingly uniform bulbs in this way.

There is, however, another method, not requiring so much skill, by which the bulbs are all made exactly of the same size. They are blown into a mould, such as is shown in Fig. 31.

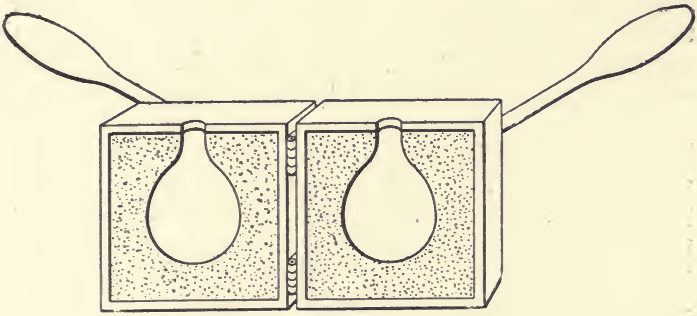


FIG. 31.—Bulb Mould.

The mould is made of iron, and is lined with plumbago. The glass worker, having gathered some glass on his iron tube, stands on a low platform or stool, and places the end of the tube with the glass on it into the opening of the mould, which a boy holds in position on the ground. He blows down the tube, and twirls it round between his hands at the same time. The glass is blown out so that it fills up the space in the mould. The boy then opens the mould, and releases the bulb, which is then cut off from the tube. Wooden moulds may be used if only a few bulbs of an odd size are wanted. Apple wood answers the purpose. The bulb is blown in just the same way. The surface of the mould quickly becomes charred or carbonised, and thereby protects the wood below the surface. A number of bulbs may be made in it before it perceptibly increases in size. Pump bulbs and the like may

very well be blown in wooden moulds, as also may the globes or shades for the flashing apparatus. For these latter the mould need not be so complete. It is sufficient if it be simply a cylinder open at both ends.

The only other article required in a lamp factory, made directly from pot glass, is glass tubing. Quantities of this of various sizes are required. Small sizes are used for making the tubes which are joined to the bulbs, and through which the air is exhausted; and larger sizes for the mercury pumps and other apparatus. The method of making the tubing is very simple. The tube begins, as most articles do, with a bulb at the end of the glass worker's iron tube. A lump of glass is first gathered from the pot upon the end of an iron rod, which is then given to a boy to hold, glass uppermost. The glass worker then gathers glass on his iron tube, in quantity according to the size of the tube he is going to make, and forms it into a hollow bulb. If the tube is to be of large diameter it will be a large bulb, and will require a good deal of rolling on an iron plate, and re-heating at the mouth of the crucible before it is of the proper shape. It must be perfectly round inside and out, or the tube will contain along its whole length any defect in the shape. Having got the bulb into the required size and form, the glass worker turns it over so that the end of it is brought into contact with the glass at the end of the rod which the boy is holding in readiness to receive it, and to which it will adhere. The iron rod and the tube are then both held horizontally, and are turned round and round, while the boy at the same time walks backwards, thus elongating the bulb, and drawing it out into a long tube. The tubing is made in this way many feet long. For a considerable length in the centre of the piece it is, probably, of nearly uniform size, though towards each end it will be larger. When it is pulled out sufficiently, and becomes rigid, it is laid on the floor across pieces of wood placed ready to receive it, and is then cut up into lengths, which are afterwards sorted into the different sizes. A good glass worker can so manipulate the glass as to produce within a very little the exact size of tube which is required.

All the rest of the work on the glass is done by glass blowers with a blow-pipe flame, and will be treated of in the next chapter.

CHAPTER X.

GLASS BLOWING.

The art of glass-blowing consists in softening glass in a blow-pipe flame, and then working it into the desired shape or form. The incandescent lamp industry has had to produce its own glass blowers. In the early days of incandescent lamp making there were few skilled glass blowers, and many of them were only skilled in making perhaps one particular article. Thus, a man who was used to making spiral-bulbed thermometers would in all probability be a very poor hand at "sealing in" a lamp filament. He would demand an extortionate rate of pay, and would work very slowly, and he would not work at all if anyone was standing by, as he would not wish to give away the secrets of his trade. It was on account of this kind of thing that Messrs. Wright and Mackie brought out their glass-blowing machine, a machine specially designed for making lamp-bulbs out of tube, and for sealing in the filaments, all without the aid of the professional glass blower. Bulbs made straight from the glass-pot—"pot bulbs," as they are sometimes called—were not made at the time. The bulbs were all made from the tube. The glass-blowing machines, however, never came into general use, partly on account of the introduction of pot bulbs and partly because it was found that a new race of glass blowers, without the prejudices of the old hands, was springing into existence. It was found that lads who were handy with their fingers could soon learn not only to seal in, but even to make good bulbs, and many of them even to do the more difficult work of making pumps. A lad or a girl at a fraction of the wage of the professed glass blower would do more work, and yet be well paid.

Complicated glass work for chemical and other apparatus, which many glass blowers were accustomed to make, is of necessity done in a very slow and deliberate manner. A moment of impatience, too quick heating or insufficient annealing of a part, might spoil a whole day's work. This is no doubt the reason why glass blowers appear to work so very slowly. Such a slow rate is, however, quite unnecessary in lamp making. The really skilled glass blowers are not found in lamp factories, for the reason that they are not required, and that it pays them much better to make chemical and other apparatus, which always commands a good wage.

The blow-pipe most commonly used in glass-blowing is that called the "cannon." Various forms of this blow-pipe, of a

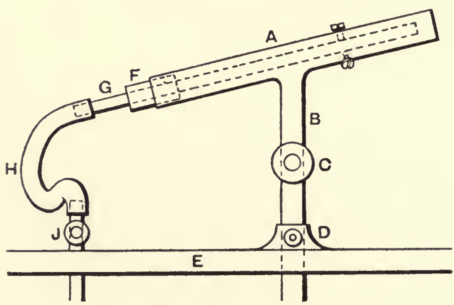


Fig. 32.—Cannon Blow-Pipe.

more or less elaborate construction, are made, but the simplest and cheapest form, shown in Fig. 32, is the most satisfactory. It consists of a piece of brass tube, A, open at both ends, joined to another tube, B, at about the angle shown in the figure. C is a screw stop-cock. D is a socket through which the tube B slides, so that the whole can be raised or lowered and fixed by the thumb-screw in D at any convenient height above the table E. Below the table the tube B is joined by a flexible tube to the gas supply. F is a cork with a hole bored through its centre to accommodate a piece of glass tube, G. About two-thirds up the tube, A, three screws pass through it and act as guides to the inner glass tube, G, and keep it in the centre. The end of the glass tube G is joined by a piece of flexible tube, H, to the air-blast through the stop-cock J.

Almost any kind and size of flame may be obtained with this blow-pipe, depending on the regulation of the gas and air blast by the cocks C and J. It is necessary, however, to use a larger bore glass tube, G, for the large flame than for the smaller ones, while for the small pointed silent flame the nozzle of G must be considerably contracted. It is a matter of importance that this glass tube be quite straight and regular and smooth inside, and that both ends of it, especially that

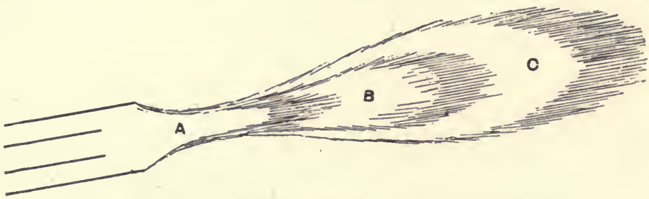


FIG. 33.—Form of Large Flame of Cannon Blow-Pipe.

from which the air issues, be cut off perfectly straight across and at right angles to the tube. This tube can be moved in and out through the cork and adjusted to its proper position. It should not reach to the end of A by a quarter of an inch or so.

In working with French or German glass, which does not contain lead, no great attention need be paid to the flame, and

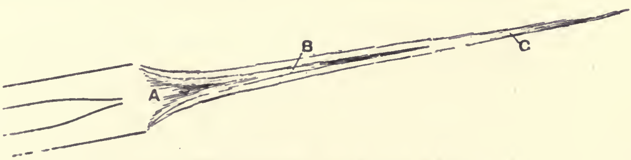


FIG. 34.—Pointed Blow-Pipe Flame.

any part of it may be used. As, however, lead glass is used almost always in lamp-making, it is necessary to take care that the flame is a suitable one, called sometimes a "clean" flame. That is to say, it must be one in which the "reducing" and the "oxidising" parts are clearly defined and are not mixed up. Figs. 33 and 34 show the forms of the cannon and the pointed flames respectively. The "reducing" flame is that part marked B. It contains an excess of carbon, while in the "oxidising" flame, C, there is an excess of oxygen.

These different parts of the flame can be easily distinguished by their appearances. The hottest part of the flame is just at the junction of B and C, at the tip of the point of B in Fig. 34.

In working with lead glass, the oxidising part C can alone be used. If the glass is held in B, some of the lead is immediately reduced to the metallic state, and colours the glass black. When this takes place it is at once seen by the lead appearing as a bright red opaque patch on the otherwise nearly transparent glass. If allowed to cool, the patch will be found to be black. When this patch of lead appears, it can easily be oxidised again by holding it further away in the C part of the flame. This, however, can only be done if the patch is superficial. If the lead has been reduced much below the surface, it is impossible to get the glass clear again. The reason for being so particular about the inner or wind tube of the blow-pipe is that a tube which is irregular in any way will impart its unevenness to the air blast, so that the oxidising and reducing parts of the flame are all mixed up, or rather there is no oxidising part. Blow-pipes with metal wind tubes, which can be purchased ready made, are generally unsuitable for lead-glass working on this account.

The blow-pipe is fixed on the table about four or five inches from the edge, and pointing directly away from the operator. The table should be covered with a thick sheet of asbestos, and this should be painted black, as the flame can be seen much better against a dark background. The glass-blowing table should not be brilliantly lighted, and the light should come from above, or from the sides, and not from in front of the operator. If there is too much light, it is difficult to see the flame, or, at any rate, the oxidising part of it, which is almost entirely non-luminous.

There is one objection to the cannon form of blow-pipe for large flames. It is very noisy. In a room with a number of them at work it is a matter of some difficulty to hold any conversation, on account of the powerful roar which they make. The small pointed flame (Fig. 34), however, makes no noise whatever, and for this reason it is better to use a compound blow-pipe made up of several small noiseless flames. This may be accomplished by fixing three or four

blow-pipes giving such flames side by side, and so directed that the tips of the flames meet each other. To obtain a greater heating power an equal number may be arranged opposite to the first set, in the reverse direction, so that all the tips of the flames meet in the centre of the space between the two sets of blow-pipes. In this way is produced an excellent and perfectly quiet blow-pipe flame, which gives a more even heating, the glass being heated on both sides at the same time, though this is not always an advantage. Such an arrangement, however, is only applicable to work which does not require a varying flame. It is suitable for sealing in

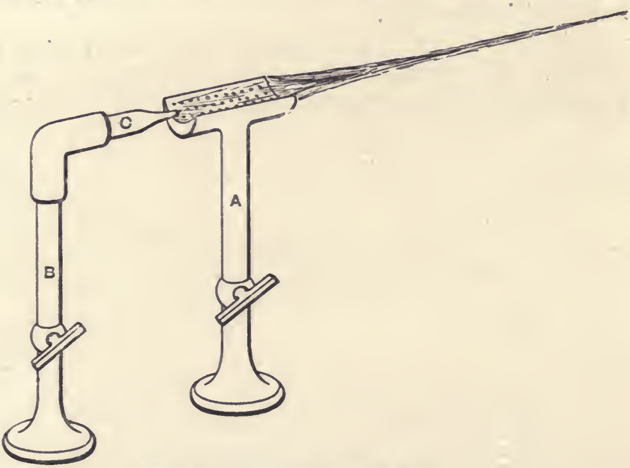


FIG. 35.—Compound Blow-Pipe.

filaments, though the pump-maker could not work with it entirely. It is certainly an advantage to have the sealing-in room quiet. Six or eight cannon blow-pipes set up together in the way just described is, however, a rather clumsy arrangement. A better plan is to use blow-pipes of the form shown in Fig. 35. A is the gas tube, B is the air tube, each of which is provided with a stop-cock. At the top A terminates in a hollow burner, through which the gas passes by a number of small holes. The air tube B terminates in a glass nozzle C. The gas issuing from the top of A having been lighted, the stop-cock in B is turned, with the result that the air coming from C blows into the luminous gas flame, and makes it

assume the pointed quiet type of blow-pipe flame. Six or eight of these blow-pipes may be arranged so that the flames are combined together, as shown in plan in Fig. 36. The six pointed flames burn no more gas than the single cannon flame suitable for the same work would do; probably they burn less. The compound form is, of course, more costly in the first instance. There are stop-cocks, controlling both the air and the gas of the whole six burners, so that, in case of any increase or decrease in the pressure of either, it is not necessary to alter the whole six or twelve cocks; in fact, when the stop-cocks in the pillars are once set properly they should not be again disturbed.

It is essential that the glass-blowing room be free from draughts, as a slight draught will blow the flame to one side, and render working difficult. As a consequence of this, the

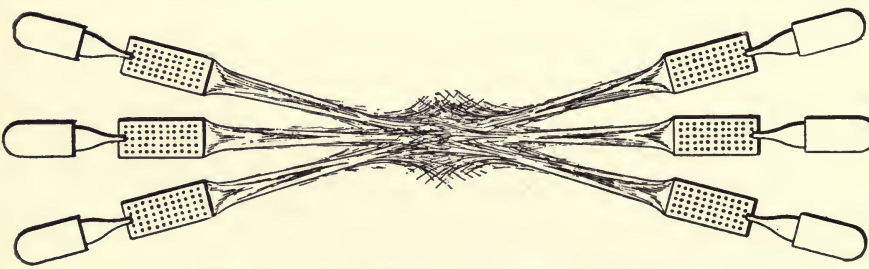


FIG. 36.—Form of Flame of Compound Blow-Pipe.

state of the atmosphere in a glass-blowing room with a number of blow-pipes working is often distressing to anyone but a glass-blower. There is no reason why a glass-blowing room should not be lofty and well ventilated, without any inconvenient draughts, but this is seldom the case. The Author, not long ago, had an opportunity of going over a new lamp factory, the building having been constructed for the purpose, and was surprised to find that even under such circumstances the glass-blowing room had a very low ceiling, and no means of ventilation whatever. The quantity of gas used by a blow-pipe is very considerable, and the ventilation should, of course, be ample and easily controlled.

Each glass-blower can, by means of a foot bellows, pump the wind for his own blow-pipe. This method has an

occasional advantage in enabling him to vary the pressure, and therefore the form and heat of the flame, without having to turn a cock. It seldom occurs, however, that one hand cannot be spared for an instant for this purpose.

The disadvantage of a foot bellows is that the glass blower cannot sit so comfortably or so steadily, both important considerations in glass blowing, when he has to keep one foot pumping up and down all the while. Moreover, the wind is apt to run out at a critical moment. If a foot bellows is used it is best to use a much larger one than the ordinary laboratory form, and to have it fixed underneath the table with a large air reservoir, in order that the blast may be steady, and not go up and down with each stroke. The bellows and reservoir should be large enough that a single stroke will supply the blow-pipe for some minutes. Such an arrangement, however, does away to a great extent with the advantage mentioned of being able to vary the force of the blast with the foot at any moment, which can only be done with a bellows of small capacity. In a factory where a large number of blow-pipes are required it is necessary that a supply of air be laid on so that the glass blowers do not require separate bellows. For this purpose a mechanical pump with a single cylinder driven by power answers very well. The air is forced into an iron tank with a blow-off valve. The pressure may very well be five or six pounds to the square inch, and the blast will be perfectly steady if the reservoir is large enough. The force of the blast is, of course, entirely under control by the screw cocks on the blow-pipes. With an ordinary foot bellows the pressure is only a small fraction of this amount, but a much larger pressure in the pipes works perfectly well so long as the rate at which the air is admitted into the flame is under control. The air should be taken from the pump into the side of the reservoir, the bottom of which should be of such a form that any water inside may drain towards one part where a cock can be placed by which it can be let off. The delivery pipe should be led off from the top, so as to be as dry as possible. In damp weather there is always water condensed in the reservoir, and if it gets into the pipes it may cause trouble at the blow-pipes. Instead of a pump, a fan may be used. Fans, however, as usually constructed, are

adapted for delivering large quantities of air at a small pressure, and are, consequently, unsuited for supplying air through long lengths of small piping. As a rule, they require a very high speed, and are very noisy.

As lamp bulbs blown from glass tubing have not altogether gone out of fashion the method of making them will be described. The cannon form of blow-pipe with the noisy flame is the best to use for this purpose. The size of the glass tube from which the bulbs are to be blown will be selected according to the size of the bulb which is required. For an ordinary 16 candle-power size it will be about $\frac{3}{4}$in. in diameter, and about $\frac{1}{16}$th of an inch, or rather more, in thickness. The tube must be quite clean inside and out, as any dirt may get so burnt into the glass that it cannot be removed. The glass tubes are usually cut into lengths of about 3ft. The glass-blower takes one of these, and, sitting himself at the table with the blow-pipe just in front of him, adjusts the size of the flame, using more gas at first than he requires for softening the glass, making thereby a flame much larger and not so hot as he will ultimately require. He then holds the glass tube with his left hand, so that one end of it is in the flame at some distance from the blow-pipe, at the same time turning the tube round and round so that it shall get heated evenly. The heating must be started gradually in this way, or the tube may crack. If the tube be a thick one it will be necessary to turn it round and round at a point beyond the flame altogether, so as to get it very gradually heated before it is brought into the flame at all. As the tube becomes heated the gas is turned down, thereby reducing the size of the flame, and making it hotter. The end of the tube, constantly being rotated, is brought into the oxidising part of the flame, and soon begins to soften. When this occurs the glass-blower presses the ends of the tube inwards with the tail end of a file or other convenient instrument, so that the sides touch one another. He then melts on a short length of small "cane" or "rod" glass. Having done this, he will heat the tube a little lower down, and when it is soft he will take it out of the flame, and, by means of the piece of cane glass, will draw out the heated part of the tube for 8in. or 10in. or so, as shown at B in Fig. 37. The part

drawn out will be narrow and thin. When the tube on which the glass-blower is working is long he cannot conveniently hold it up and work it at the same time. A rest must therefore be provided to hold one end of it. If the end is allowed to lie on the table it will roll along as the tube is rotated. The rest must therefore carry a groove or notch in which the tube can turn without rolling along. Having drawn out the end of the tube, the piece of cane used for the purpose is no longer required, and may be detached. The tube is then heated about 3in. lower down and drawn out as before for 15in. or so (C, Fig. 37). This is done by means of the first piece drawn out, which, being thin, quickly cools enough to allow of handling. The tube is then cut at the

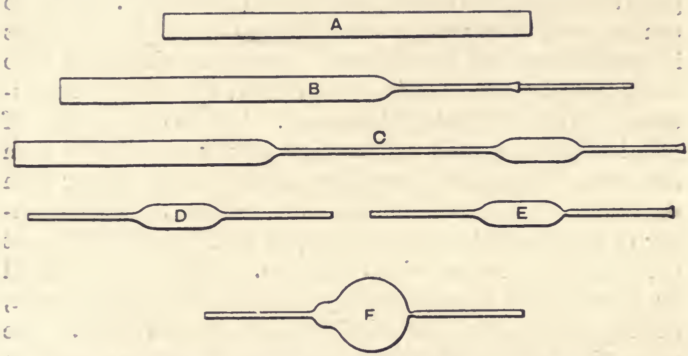


FIG. 37.—Different Stages in Blowing a Bulb from Glass Tube.

centre of the narrow part of the second drawing out, leaving a piece of the original tube about 3in. long drawn out at each end into a small tube, D. The glass is cut by first scratching it with a file and then pulling it, when it will part at the scratch. The process of drawing out and cutting off is then repeated until the whole of the tube has been converted into pieces similar to D. Each of the pieces will make a bulb. The next operation is to close up one end by heating in the flame. This is easily accomplished, as the glass will close up of itself as soon as it becomes soft. When this is done, the narrow tube, which has not been closed, is heated close to its junction with the full-sized tube, so as to make a contraction in the bore, E. This is the point

where the lamp will be eventually sealed up after pumping. Nothing remains now but to form the bulb. For this purpose a rather larger flame is required, and is made to play upon the thick part of the tube, E, rather nearer to the contracted end than the other. As the glass softens it caves in all round, and the glass-blower pushes the smaller tubes inwards, so as to get the soft glass into a smaller space, and to get it better covered by the flame. When it has attained the exact degree of softness, which is ascertained as much by the feel as the appearance, he takes it out of the flame, and holding it with the open end to his mouth in a horizontal position and quickly rotating it all the while, he blows into it with a series of short quick puffs, thereby blowing out the softened glass to any required extent, and forming the bulb F. The bulb can be made of any shape according to the way the soft glass is manipulated and blown into. Success in blowing a bulb depends on the even heating of the glass, and skill in manipulating it while it is being blown into. It takes a good deal of practice before a good symmetrical bulb can be made with certainty. Beginners invariably make one side larger than the other. If a large bulb is to be made from tubing, a quantity of glass must be run together, so that it is very thick at the place where the bulb is to be blown. This is accomplished by pressing the tube lengthways towards the softened part, thereby bringing in more and more glass into the flame. The exhausting tube of the bulb F should be closed up as soon as the bulb is finished, to prevent dust from getting inside. Bulbs blown from tubing as described have this exhausting tube already attached. Pot bulbs, however, have no such tube, and one must consequently be joined on. This has to be done before the filament is put in, as the tube is necessary for holding the lamp during that operation. Tubing of the required size, about $\frac{1}{8}$in. diameter, is cut up into lengths of about 6in. An indiarubber cap is slipped over the neck of the bulb to make it air-tight. The end of the bulb where the exhausting tube is to be attached is then held in the blow-pipe flame, being rotated as usual, so as to soften a small part of the glass just in the centre. By the time this spot is soft, the air confined within the bulb has become heated, and therefore exerts a pressure outwards, which is

sufficient to blow the softened part outwards and make a hole right through. The bulb is usually held in the flame and rotated by the left hand, while at the same time the right hand is heating the tip of one of the 6in. glass tubes. As soon as the hole appears in the top of the bulb the softened end of the tube is stuck over it, and the junction is held in the flame and thoroughly worked and melted together, and to assist the operation it is several times blown into and swelled out and reduced down again, finally being left contracted close to the bulb, as in the case of the tube-blown bulbs. If the bulb is not required for use for some time the ends should be sealed up.

CHAPTER XI.

SEALING-IN.

"Sealing-in" the filament is the next process to be described. The precise details of the process depend upon the way the filament is mounted, or whether the platinum wires are joined together by glass in any way, and whether the lamp is to be "capped," or is to have the platinum wires formed into loops at the bottom or sides of the neck of the bulb. First of all, the exhausting tube, if closed up, must be opened by cutting off the tip. This tube is now used for holding the bulb, and it makes a very convenient handle by which to rotate the bulb in the flame. The neck of the bulb is then heated by rotating it in the blow-pipe flame, so as to soften the glass at a short distance from the bulb. When soft the superfluous piece of neck is pulled away with the right hand, while the left still holds the bulb in the flame, so that the piece of neck is severed from the rest, leaving the bulb with the short remaining neck closed up. If too long a neck still remains, more may be removed by again heating and drawing it off by means of a small piece of glass rod or a bit of waste glass from a former operation. The end of the short neck has now to be opened for the reception of the filament. It is again held in the flame, and when soft the small tube is blown through somewhat violently, so that a hole is blown or a large and very thin bulb is formed, which can easily be removed with the end of a file or other instrument (A, Fig. 38). The opening produced is probably too small to get the filament through, and it must therefore be enlarged. This is done by pressing out the sides when soft with the end of a file, as at B. One of the glass-blower's most useful tools is a small fine file, as with it he

can scratch the glass in order to cut it at any point, while the end which is intended to go in a handle can be used for moulding the glass when soft. The filament already mounted on the platinum wires is next carefully inserted through the opening. It may be handled by the wires by means of a small pair of pliers. When far enough in the bulb the wires are held against the glass at the end of the opening and held in the flame. As soon as the glass at the point of contact is soft, the wires will adhere to it, and the pliers can be laid down. The next thing is to close up the opening. It will close up of itself if sufficiently heated, but it may be assisted by pinching with a pair of spring nippers made for the purpose. If this is done there will be rather large corners formed, as in C,

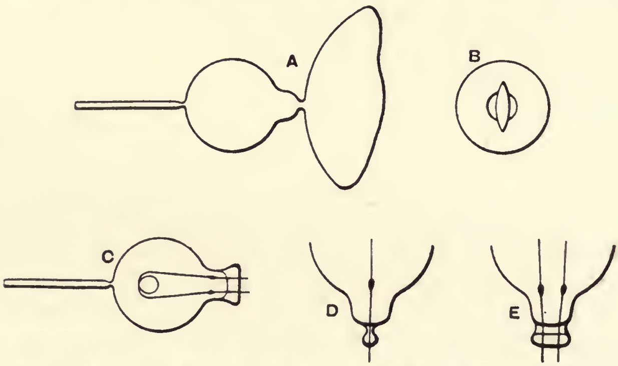


FIG. 38.—Different Stages in the Process of "Sealing-in" the Filaments.

which can be cut off while soft with a pair of cutting nippers. To make the seal good and neat it will require several times heating and blowing out by blowing through the small tube.

If the lamp is to be "capped," the end must be formed so that the plaster used in the cap will have a good hold on the lamp. It must be shaped so that it can neither be pulled out of the plaster nor twisted round in it. The simplest way of insuring this is to make a flat piece in the way just described with a thickened end, as in D and E. The flat end prevents the lamp from turning round, and the thickened part is surrounded by the plaster and cannot be pulled out. The thickened end may be made by melting a piece of glass rod,

and winding a string of the semi-fluid glass round the end of the flat piece. Or, if the glass in the neck of the bulb be thick enough, it may be simply squeezed upon the wires, but squeezed thinner close to the bulb than at the end where the wires come through.

Some glass-blowers adopt a somewhat different method of sealing in. The filament is inserted in the opening in the bulb, as before, but is allowed to slip inside, wires and all. The neck is then heated, and drawn down quite small, and sealed up. A small hole is now made in the end by blowing through as before. The bulb is tipped up so that the wires protrude by the required amount. The small opening is then easily closed up as before. This is rather a neater method than the other, but is more likely to injure the filament. If the wires are to be formed into loops, they may be bent into shape before the filament is put into the bulb, or the loops may be formed after the seal is made. The first method produces the most uniform loops. Care must be taken in forming the loops that they are of equal size, or there may be a difficulty in making contact with the holder to which the lamp will eventually be attached. If the wires are to be brought out at the sides of the neck, a similar method may be used, the filament being inserted as before, and the ends of the wires pushed back through small holes made in the neck. Another method is to cut the neck off at the place where the wires are required to come out, and then to put in the filament with the wires reaching over the sides and melt the neck on again.

In an ordinary flint glass works an important piece of apparatus is the annealing oven. Glass which has been worked into various shapes and joined to other glass requires to be very slowly cooled down. It is put into the annealing oven, and given, perhaps, several days to gradually cool to the temperature of the air. If allowed to cool rapidly it will probably crack either before it is quite cold or after an interval of, perhaps, days or weeks. In lamp factories no such annealing ovens are necessary. If really good glass is used, and the seal is properly welded, no annealing whatever is required. The seal may be allowed to cool as quickly as it likes. It is, however, customary to anneal to a slight extent. It may be

done by using a kind of oven made of sheet iron, the whole thing being quite small, each glass-blower having one on his bench. The top is capable of being rotated, and has four circular holes in it. Below three of the holes is a Bunsen gas burner with a rose top. One is turned up fully, the next has a smaller flame, and the third a still smaller one. When a lamp is sealed in, it is placed, seal downwards, in the hole over the largest flame. The hole is of such a size that the lamp rests about one-third through it. The seal is, therefore, prevented from getting cold at once. When the next lamp is sealed in, the top of the oven is turned round, so that the first lamp is brought over the second gas burner, which will allow it

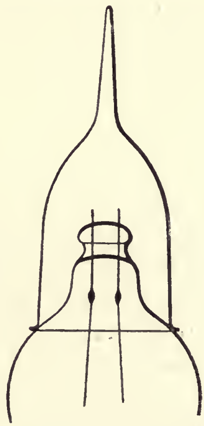


FIG. 39.—Lamp with Annealing Cap.

to cool a little more, and the new lamp is placed in the next hole, which is now over the first burner. The next lamp is treated in the same way, and put over the first burner, while the others are turned round, so as to be over the second and third respectively. On a fourth lamp being sealed in, the first one will be over no burner at all, and will get quite cold, and when a fifth lamp is ready the first is taken out of the annealer and put away. In this way a lamp is made to cool gradually in about a quarter of an hour, and this is quite a long enough time if the glass is good and the seal well made. Another method is to put a glass cap or cover over the seal (Fig. 39). This cap has been heated over a Bunsen burner while the seal

was being made. By this means the seal is prevented from cooling quite as rapidly as it would if the cold air were allowed free access to it. Some glass-blowers anneal by holding the lamp or other article just made in the smoky flame from the blow-pipe with the air blast shut off. The result is that the glass is covered with a coating of lamp-black, which is supposed to keep it warm and allow it to cool only slowly. It seems highly probable, however, that it has precisely the reverse effect. In any case it is a dirty method, and one not to be recommended.

A very troublesome occurrence sometimes takes place in connection with sealing in the filaments. When the lamps are being exhausted it is found that the bulbs are spotted all about on the inside with dirty white spots, and they are in consequence unfit for sale. The bulb is wasted, though the filament can be taken out and put into another bulb. The appearance of these spots is not altogether easy to account for, as they only occur occasionally. Perhaps during one day a number of lamps may be found in this condition, though previously they had been quite free from it. It has been suggested that it is caused by the glass-blowers chewing tobacco, but the Author has found it to occur in lamps sealed in by girls who resented the imputation of chewing tobacco. The spots resemble those which may often be seen on the chimney glasses of argand gas burners, and there seems to be little doubt but that they are due to a similar cause. When an argand gas burner is first lighted, drops of water, produced by the combustion of the gas, condense upon the cold chimney. This water soon evaporates as the chimney gets warm, but before it has done so it has dissolved certain other products of the combustion of the gas, and these it leaves behind on the glass in the form of spots exactly where the drops of water were located. When an argand burner has been lighted a number of times without the glass being cleaned, these spots are very apparent, as they are added to at each time of lighting. The spots on the inside of the lamp bulbs are like these in appearance, and are probably due to a similar cause, though their appearance on some days and not on others is somewhat perplexing. In order to be due to the same cause it is, of course, necessary that the products of combustion of the gas of the blow-pipe flame get into the bulb,

which can easily happen during the sealing-in. During the sealing-in, however, the bulb is too warm to allow of any moisture condensing upon it; but, nevertheless, the air within it is extremely moist, partly from the water produced by the flame, but more from the glass-blower blowing into the bulb so many times during the process of sealing in. When the sealing in is done and the lamp cools down, the moisture will condense upon the inside of the glass, and this moisture is ready to absorb anything there may be within the bulb. When this moisture is driven off, either by again heating the bulb or exhausting the air, the solid white matter is left behind in the form of spots on the bulb, precisely as it is in the case of the argand chimneys. The question, however, arises, why should not the same thing always happen. When it does occur, it generally does so with the work of several glass-blowers at the same time. Consequently, the cause must lie in something which affects them all. This can only be in the quality of the gas itself, or of the air blast. It may be that the gas on some days contains impurities which are absent on other days. The air blast cannot very well contain anything unless it is water. Water in the air blast may possibly effect the combustion of the gas.

The remedy for the trouble is simple enough. The bulbs must not be allowed to cool with this mixture of gases and moisture inside them. Instead of the usual annealing they must be taken as soon as sealed in, and placed in a hot oven, which may be heated with steam pipes, until they can be dealt with. They are then taken one at a time and exhausted by a mechanical air pump, an operation only taking a few seconds. The lamps, hot from the oven, are connected by rubber tubes through a three-way cock, to a vacuum pump, and exhausted, and then refilled with pure dry air. In this way no moisture is allowed to condense on the glass and spots are entirely prevented. Such precautions are, however, unnecessary, unless it is found that the lamps are apt to become spotted. The process of mechanically exhausting the bulbs after sealing-in and re-filling them with dry air is, however, one which may be adopted with advantage in any case. There is usually a film of moisture on the inside of the bulb after sealing-in. If the lamps are connected to the

mercury pumps in this condition, the phosphoric anhydride drying tubes will require very much more frequent renewal than they will if the above method is adopted.

Before leaving the subject of glass blowing, there are one or two points in connection with it to be mentioned.

Glass tube is "cut" by making a scratch on it in the direction in which it is to be cut, and then pulling it apart, and at the same time pressing the scratched part outwards. In this way it will usually part straight across and perfectly evenly. The scratch may be made with the edge of a file. A small, fine, flat file (not a three-cornered one) answers best. After a while the corners of the file will get blunt. The thin edges of the file must then be ground slightly, and the four cutting edges will again be sharp. A file is not necessary. Any piece of hard steel ground to a somewhat sharp edge will do. A razor ground so that it is just about sharp enough to cut cheese will scratch glass very well. A properly sharpened razor will not do it.

When the tube is too thick, or its situation will not allow it to be pulled apart after the scratching, it may be severed by applying to the scratch a small globule of melting glass, formed at the end of a piece of thin drawn-out glass, such as may always be found on the glass-blower's table after he has been at work a short time. This will start a crack, and the tube can then be severed with very little force. In order that the crack shall be certain of going in the right direction it is advisable to scratch the glass all round instead of only for a very short distance. In cutting large articles like the glasses used for flashing-in, a crack may be started in the above-mentioned way, and may then be led round in the direction required by holding against the glass a hot piece of metal, like the end of a file or a piece of wire, slightly in advance of the end of the crack, which will rapidly follow it.

There are other methods which may be used for cutting such large articles. For instance, a string may be tied round the article, and be moistened with spirits and lighted. If a scratch has been previously made at some point under the string, a crack will be started there, and will probably extend all the way round exactly in the line of the string.

The glasses used for flashing-in have to be ground in order that they may be perfectly flat on the ends, or it will be impossible to obtain in them the necessary degree of vacuum. The grinding is done on the flat side of a grindstone. The "stone" may be made of wood or lead. An iron shell filled with lead answers very well. Fine emery powder with water is used on the lead. The glass to be ground is held firmly and lightly on the stone, and moved about to and from the centre, care being taken to keep it always perfectly upright, or it will not be ground flat. It must be ground until the whole of the edge has come into contact with the stone. When ground sufficiently, the edge may be smoothed by further grinding or polishing on another (wooden) wheel, using powdered pumice instead of emery.

Stoppers, taps, and valves required for pumps and other apparatus have also to be ground. When the bearing, or rubbing surface, of the two parts is not large, as in the case of pump valves, the two parts may be directly ground together, using fine emery powder and water or turpentine. The glass valve can usually be welded to a piece of glass rod, by means of which it can be ground round in its seat. This may be done by hand, but it is much quicker to fix it in a lathe, and, if the parts have been well made, very little grinding is necessary. On a glass-blowing machine it is possible to make valves so perfectly circular as to need no grinding at all. Such a valve with a little mercury round it will hold a vacuum without leaking against the full pressure of the atmosphere. Hand-made valves, on the contrary, are seldom, if ever, so perfect but that the mercury is speedily forced through under the same circumstances, and they consequently have to be ground.

The two parts of articles like stoppers and stop-cocks which have a large extent of bearing surface are best ground separately in the first instance and then finally together. A hollow cone and a plug to fit it, of the shape required for the stopper or cock, are made out of copper, and are used to grind the glass with until the whole of the surfaces have been ground over. The two glass parts are then finished by grinding them together. Care must be taken in lathe grinding that the glass is not allowed to get too hot or it may crack. Great care

must also be taken that no undue strain is produced. The part turned by the lathe must be so fixed that it will slip if there is any tendency for the two parts to jamb together, or else the other part must be so loosely held that in case of it seizing it can rotate with the rest. Glass cocks can be bought cheaply, and are seldom made in the lamp factories. Those which are usually sold, however, are made of German glass, which has no lead in it. It is difficult to join this glass to lead glass satisfactorily, although it can be done. A joint between two very different kinds of glass is always liable to fail, even though it appears to be perfectly welded.

CHAPTER XII.

EXHAUSTING.

The filament having been sealed into the bulb, the next process is that of exhausting the air. This process is, perhaps, the most important of all, as upon the excellence of the vacuum produced depends, to a very great extent, the life of the filament. It is, moreover, the most costly per lamp of any of the processes.

It is necessary that the air be removed from the bulb, primarily, on account of the combustible nature of the filament. If a carbon filament is heated to incandescence in air, by a current of electricity, it rapidly burns away. Even if the air is removed as far as possible by exhausting with a good mechanical air-pump, there will be sufficient left behind in the bulb to burn the filament enough to speedily cause its breakage. It is necessary to produce a very much better vacuum than can be obtained by any ordinary mechanical vacuum pump. A very small quantity of air left behind in the bulb will be enough to burn the filament slightly, and thereby shorten its life.

It has, at various times, been proposed to fill the bulb with nitrogen gas, and then to only partially exhaust. In this way a residual atmosphere of nitrogen could be left behind, which would be incapable of burning the filament. Another advantage of this method would be that the exhaustion, not requiring to be carried to a very high state, could be done very quickly with a mechanical air-pump.

There are, however, several reasons why this method cannot be successfully used. The combustion of the filament with the oxygen, in the case of a residual atmosphere of air, is not

K 2

the only action which has to be considered. In a lamp containing a residual atmosphere of air, nitrogen, or any gas, there are convection currents set up in the gas within the bulb, which consequently becomes very hot. The gas is heated by contact with the white hot filament, and a continual circulation is kept up from the filament to the bulb, and back again. The bulb, in consequence, becomes so hot that it cannot be touched, and it will char wood or paper, or anything of a combustible nature with which it may be in contact. One of the most cherished attributes of the incandescent lamp is that it gives off very little heat, and is perfectly safe, and can be handled with impunity when lighted, and may be placed with safety anywhere, even with very inflammable material in close proximity. All these advantages are lost when the vacuum is not perfect. No residual gas can be allowed in the bulb. Besides making the lamp very hot, there are other objections to the residual gas. Unless exactly the same pressure of gas be left in all the lamps, they will vary in brightness, even though the filaments are exactly alike in every particular. Lamps with a greater pressure will be duller than those with a less. The heat of the filament will be carried away to the glass by the currents of gas more quickly, and a higher voltage and current will be necessary to maintain a given temperature. In a properly exhausted lamp the effect of convection currents is negligible, because there are practically none. But with a vacuum below the proper standard convection currents begin, and have a rapidly increasing effect in cooling the filament, and the poorer the vacuum the more power must be supplied to the filament to maintain the temperature. Consequently, at a given temperature, a lamp with a poor vacuum is less efficient than one with a good vacuum at that temperature. It takes more power to produce a given quantity of light. Such a lamp, with a poor vacuum, can, however, be run brighter and brighter until its efficiency in watts per candle is equal to that of the properly exhausted lamp, but its temperature is, in consequence, very much higher.

When the vacuum is not good, and there are consequently convection currents set up within the bulb, the law of $c \propto d^{\frac{3}{2}}$ does not appear to apply, or, at any rate, it becomes useless for the practical purpose of calculating the sizes of filaments.

The actual amount of the effect of convection depends not only on the pressure of the gas but on the size of the bulb. If the bulb is small, the gas within it will get much hotter, and the filament will also be hotter than if the bulb is large, when there is a greater quantity of gas to be heated and a larger surface of glass for it to cool against. It, therefore, becomes necessary that the vacuum in a lamp shall be so far perfect that convection currents are absent altogether. In order to produce such a vacuum it is necessary to use what are known as mercurial air-pumps, mechanical air-pumps not being good enough for the purpose. Of course it is impossible to obtain a theoretically perfect vacuum, but with the mercurial air-pump such a degree of exhaustion can be produced as to reduce the pressure of the gas to something unmeasureable, and to entirely remove all signs of convection.

The mercurial air-pump, although only within the last few years brought to a state of efficiency—it cannot yet be called perfection—is by no means a recent invention. It was used more than two hundred years ago. In the seventeenth century, Torricelli showed how a vacuum could be produced by filling a tube, something over 30in. long and closed at one end, with mercury, and then inverting it, while temporarily closing the open end, and placing that end under the surface of mercury contained in a cup. The mercury in the tube then descended until it stood at what is now called the "barometrical height" above the level of the mercury in the cup. The enclosed space within the tube above the top of the mercury contained, therefore, a vacuum, as in an ordinary barometer. A vacuum so produced is always now called a "Torricellian" vacuum.

Progress from that time was slow. It was not until 1865, when Sprengel brought out his well-known form of pump, that high vacua were easily obtained, although, ten years previously, Geissler had invented the pump which is called by his name, and which, in a modified and improved form, is now found to be equal, if not superior, to the Sprengel pump.

Anyone who wishes for full information on the development of the mercurial air-pump from the time of Torricelli must study the lectures delivered in 1887, before the Society of Arts, by Prof. S. P. Thompson. A reprint of these lectures,

from the *Journal* of that Society, is published by Spon. Anyone reading these lectures will understand that the modern forms of pumps are in no case the invention of any individual person, but are the outcome of improvements made by a number of people at various times.

Prof. Thompson classifies the pumps under several heads, the two principal ones being (1) upward driving pumps, and (2) downward driving pumps. Geissler's pump comes under the first heading, and Sprengel's under the second. It is with these two forms of pump in some shape or other that the lamp-maker is concerned.

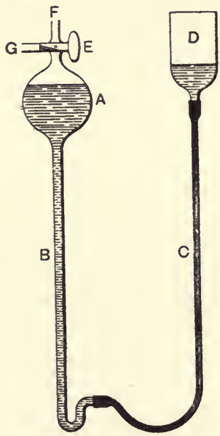


Fig. 40.—Geissler Pump.

Geissler's Pump.

The original form of Geissler's pump is shown in Fig. 40. A is a large bulb (unless otherwise stated, the parts of the pumps described are all made of glass), B is a tube some 3ft. long, on the end of which is fastened a flexible rubber tube, C, which is again connected to the lower part of a vessel, D, which is also open at the top. Above the bulb A is a cock, E, by means of which the bulb A can be connected, either to the tubes G or F, but not to both at the same time, or it can be shut off from both. The vessel to be exhausted is connected to G. F is open to the air. A sufficient quantity of mercury to rather more than fill A, B and C is poured in at D. The vessel D is capable of being raised and lowered.

The action is as follows:—Let it be supposed that the vessel D is raised up rather higher than A, as shown in the figure. The bulb A is consequently filled with mercury, while D is empty; the cock E being turned so that A is connected with the outside air at F. This cock is then turned so as to connect A, through the tube G, to the vessel to be exhausted, the air in which is, of course, at this stage, at atmospheric pressure. D is then lowered, and the level of the mercury in A is lowered in consequence, the mercury running down B and through C into D. As the mercury in A descends, air is drawn from the vessel to be exhausted through G into A, so that, when the mercury has descended below A, the whole space is filled up by air drawn through G. This air, having expanded from the closed vessel attached to G, is, of course, at a less pressure than that of the atmosphere. The cock E is then turned so as to cut off communication between A and G. D is then slowly raised, and the mercury flows gradually back into A. As the mercury rises in A, it compresses the air above it. When it has got some distance up, the pressure of the air in A will be equal to the atmospheric pressure. When this is the case, the cock E should be turned, so as to connect A with the outside air through F. The vessel D being continually raised, the mercury, also constantly rising in A, drives the air above it out at F until it is all expelled, and the mercury fills up the whole space to the cock E, which is then turned so as to cut off all communication between A and F or G. D is then lowered again, but the mercury in A does not begin to descend until D is some 30in. below A. As the mercury in A descends, it leaves a vacuous space above it; a Torricellian vacuum, in fact. The mercury having entirely run out of A, the cock E is again turned, so as to connect A through G to the vessel being exhausted. The air remaining in that vessel again expands and fills A. The cock E is again turned off, and D is raised, the mercury again rising in A, and driving the air before it until it is let out at F by again turning the cock. By successive operations in this way a vacuum is gradually produced in the vessel connected to G, that proportion of the air which expands into A being taken out at each stroke. A pump like this requires very careful working. When the exhaustion is well advanced,

great care must be used in lifting the vessel D gently, or the impact of the mercury against the glass, when it rises to the top of A, may break the apparatus.

When the vacuum is well advanced, the mercury in A will have reached the top when its level in D is 30in. below. If connection be then made with F, there will be an in-rush of air through F, which will drive the mercury down again. Communication with the air through F must, therefore, not be made until D has been raised, so that it is level with E. Communication with G must also not be made until D has been again lowered 30in. below A, or mercury will be forced through G into the vessel being exhausted.

There is, however, one great objection to this pattern of pump. Air is certain to leak into the pump part to stop-cock E. It is, in fact, impossible with such a pump to produce a vacuum sufficiently good for incandescent lamps.

In 1880 Lane-Fox produced a modified form of this pump (Fig. 41).

Instead of the three-way cock above the bulb, he used a stopper F to connect A with the outside air. The lamps to be exhausted were connected by the tube G *below* the pump bulb instead of above it, the tube G being carried upwards more than 30in. above the stopper, to H and down to K. The stopper F was sealed by mercury in a cup formed immediately above the seat of the stopper. This form of pump is better than the one first described, on account of having a direct communication, without any stop-cock, to the vessel to be exhausted, and by the fact that the stopper F could be sealed with mercury. It is, however, extremely difficult to obtain a high degree of vacuum with a pump opening directly to the air in this way.

The method of working this pump is similar to the last. When the lamps to be exhausted have been connected at K, the vessel D, being full of mercury, is lifted, the stopper F being raised. The mercury rising in A drives the air before it and out at F. When the mercury has reached to the height L in the cup above the seat of the stopper F, the stopper F is inserted, so as to retain some of the mercury in the cup to help to keep it air-tight. The level of the mercury in D is then the same as in L. The mercury has also risen in

the tube H, but not to the height of L, because the air which it drives up the tube G, H, K, is unable to get out. D is now gently lowered. The mercury in A would not descend until D was 30in. below it but for the fact of the connection to the lamps at G. When, however, D has been lowered only a short distance, and before the mercury in A has parted contact with

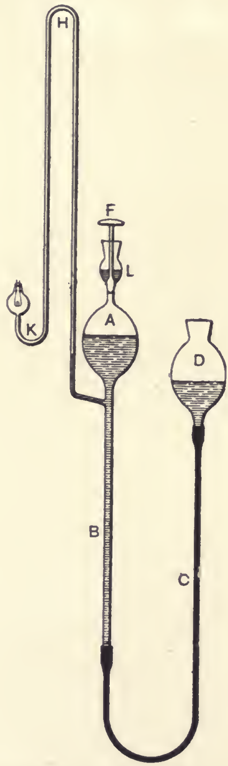


FIG. 41.—Lane-Fox Pump.

the stopper F, the air in K, H, G runs round into A, and bubbles up through the mercury. Great care is necessary in lowering D steadily and slowly, or the rush of air from G through the mercury may cause sufficient commotion to break the glass. D is gradually lowered until the mercury is all out of A. The operation is then repeated a number of times,

until the pump ceases to take any more air out. After the first half-dozen strokes or so the mercury rises in G, H, so as to be about 30in. above the level in D. Hence the necessity for carrying H more than 30in. above L, to prevent the mercury from running round into K.

A very much better pump than either of the foregoing is one known as Toepler's (Fig. 42), which, curiously enough,

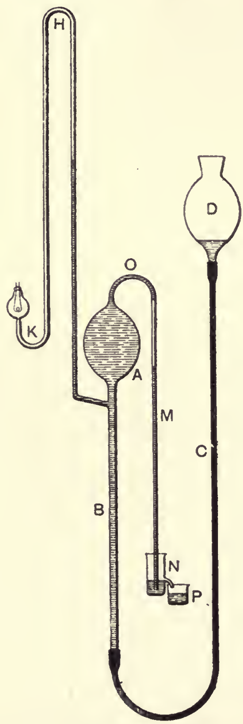


Fig. 42.—Toepler Pump.

was invented before the Sprengel pump. Toepler's pump, if properly made, is capable of producing as good a vacuum as the Sprengel pump. It is like the pump last described, except that, instead of the bulb A opening to the air through a stopper, there is a tube M of small bore joined on and carried downwards rather more than 30in., and terminating near the bottom of a cup, N.

The great advantage of this form of pump over those already described lies in the fact of the stopper, or cock connecting the pump bulb with the outside air, being entirely done away with. As the vessel D is raised, the mercury rises in A, and drives the air before it through the tube M and out at N; D is raised high enough for some of the mercury in A to flow through M into N, and so drive all the air out at N. In this way a little mercury passes at each stroke into N. When the depth of mercury, thus carried into N, is about an inch above the end of the tube M, all further amount carried into N overflows into the cup P, from which it is poured back into D.

The air having thus been all expelled through N, the tube M and the bottom of the cup N being full of mercury, the vessel D is lowered. The mercury in the tube M consequently parts somewhere about the point marked O, one part descending in the tube M and the other part in the bulb A. The mercury in the tube M will then stand at the barometrical height above the level in N. The height of the mercury in this tube gives, therefore, an indication of the degree of exhaustion in the bulb A, and when the mercury has descended in A below the tube G, the height in M gives also an indication of the degree of vacuum in the lamps.

The inside diameter of the tube M must be small, so that the descending mercury entirely fills it. When the exhaustion is only in the first stages, the mercury rising in A will force the air above it into the tube M, thereby driving the column of mercury in M down. When the mercury is thus driven entirely out of M, the air following it will bubble up and escape through the mercury in N. This will begin to happen before the mercury rising in the pump has arrived at the top of the pump bulb A. Each time the mercury is raised, less air remains to be pumped out. After a while, therefore, the mercury ascending in A will enter the narrow tube M, before the column in M has begun to descend. The column in M may only begin to descend when the mercury passing through A has arrived within, say, 6in. of it. All the air being taken out at that stroke is, therefore, contained in 6in. length of the small tube, and this 6in. length of air is under only a very slight pressure at the top of the tube. As it is driven lower

down, it is gradually compressed, and becomes shorter and shorter, so that, by the time it reaches the bottom of the tube M, it is, perhaps, only an inch long, and it has become compressed to atmospheric pressure by the time it escapes through the mercury in N.

After a while, when the exhaustion is still better, there will be, perhaps, only 1in. length of air between the top of the mercury in M and that coming from A at the moment when the column in M begins to descend. If this inch of air is watched closely as it descends, it is seen, as before, to get shorter and shorter, and it may very likely be seen to disappear altogether before it reaches the outlet. This total disappearance of the air, before it gets to the outlet, may sometimes be due to its getting compressed to such a small size that it is no longer large enough to fill the bore of the tube. The small bubble thus produced may be swept down the back part of the tube and therefore escape without being noticed. Often, however, it is certain that no such small bubble of air passes out at all, but the peculiarity is due to the fact that some of the air sticks to the sides of the glass tube all the way down. Consequently, when there is only a very small quantity at the top of the tube, there may be none at all left to pass out at the bottom, it having all adhered to the glass, where it remains as a film between the tube and the mercury. This is the great defect in this type of pump. By keeping on pumping long enough, however, the air is gradually swept off the tube, and a good vacuum can be obtained.

Care must be used in raising the mercury, as in the other two pumps described, so as not to bring it violently into contact with the top of the pump. It must also be lowered with care at starting, on account of the rush of air from the lamps into the pump, as in the Lane-Fox pump.

Fig. 43 shows a method of overcoming this last trouble. The tube G, leading from the lamps, instead of entering the tube B directly, is led into another tube P which opens into the pump just above and just below the bulb A. Therefore, when the mercury is descending in A, the air from the lamps passes from G, up P, and so enters the bulb A at the top instead of below the mercury. Thus the large quantity of mercury in A is not violently shaken up.

Sometimes a valve is used in G to prevent the mercury from rising in that tube. The long extension of G is, therefore, unnecessary. There is, however, no great advantage in such an arrangement, and the cost of the valve is much greater than that of the extra length of tube.

A great improvement in this class of pump is obtained when the air is expelled by the mercury into an already partially exhausted chamber, instead of directly into the air. An excellent pump of this kind (Fig. 44), was designed by Mr. J. Swinburne. A small bore tube, E, is joined to the top of the pump bulb A, as in Toepler's pump. This tube is bent over in the manner shown, and opens into a small bulb F, above which there is a valve K.

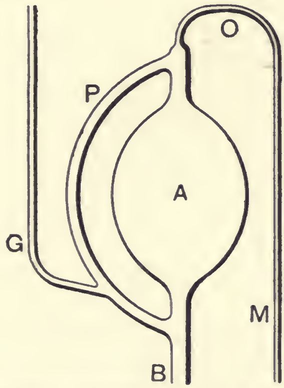


Fig. 43.—Safety Side Tube Arrangement for Use with Geissler Class of Pump.

The pump, with the lamps attached at L, is first exhausted as far as possible by a mechanical air-pump, the connection to which is made at H. As this exhaustion proceeds, the mercury rises in the shaft B, until it reaches nearly up to the point where the tube G enters the shaft B. Its height is then, if the mechanical pump is a good one, about 30in. above the level in the reservoir D. The pump and the lamps connected to it are, therefore, exhausted, as far as the mechanical pump is capable, before the mercury is used.

The reservoir D is now raised, and the mercury rises in A and G, driving the air before it through E and F, past the valve K, and out at H. D is raised high enough to carry the

mercury into the valve chamber. The valve floats upon the mercury. D is then lowered, and the mercury in the valve chamber descends, but the valve is heavy enough to reach its seat and close the outlet before all the mercury has run out of the valve chamber. The valve is, therefore, sealed by a ring of mercury in the same way as the stopper in the Lane-Fox

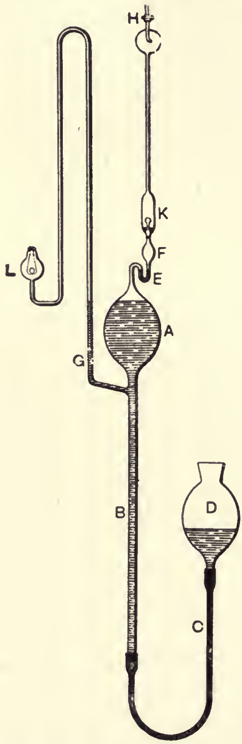


Fig. 44.—Swinburne Pump.

pump. On the mercury descending further it leaves a very perfect vacuum below the valve. The small tube E, being shaped as shown in the illustration, retains the last portion of the descending mercury, and thereby forms another seal or valve.

As the mercury descends in A there is no rush of air from G. The mercury descending in G will be nearly on a level

with that in A, even at the first stroke, provided that the preliminary exhaustion by the mechanical pump was good. Consequently, when the exhaustion is begun in this way, with a mechanical pump, there is no need for the extra side tube P, Fig. 43.

One great advantage of exhausting into an already partially exhausted chamber is that the mercury reservoir D does not require lifting so high. If the chamber K were open to the air this reservoir would have to be raised up to the level of K, in order to lift the valve. When, however, a good mechanical vacuum is maintained in K, it will only require to be raised to a height about 30in. below K, and when the reservoir is down, the level of the mercury in it will be about 30in. below the junction of G with B. It will only require to be lifted so that the level of the mercury in it is raised by a height equal to the distance of the valve chamber above the junction of G with B. This will be only about 15in. or so instead of 45in., if the mechanical vacuum were not used.

In working this pump, when the exhaustion is well advanced it is not necessary to drive the mercury into the valve chamber at every stroke. When there is a very little air being taken off at each stroke, the amount of it can be seen by the space it occupies in the tube E as it is driven along between the mercury remaining in that tube and that which rises from A. When the amount carried up at each stroke is small, it is sufficient to drive it into the small bulb F only, where it will be shut in by the mercury seal left in the tube E. A dozen strokes or so of the pump may be made, each time putting a little air into F before the pressure in F is sufficient to break the seal in E. When there are signs that this is going to occur the mercury must be raised higher, so that the air contained in F is driven past the valve.

This pump will give a very good vacuum indeed, but it is more suitable for the laboratory than for the factory, as it must be handled very carefully in order that the rising mercury shall not break the tube E. For factory use, Mr. Swinburne dispenses with the tube altogether, the valve and the bulb F being then in a line with the centre of the pump bulb A. The pump will then safely withstand the rougher usage of the factory, and it will, if properly worked, give an

equally good vacuum. The Author has used this type of pump a good deal for factory work, and it will be further described when dealing with pumps as arranged for the factory.

The Sprengel Pump.

The illustration (Fig. 45) shows the simple form of the Sprengel pump. A is a funnel below which is a stop-cock, C. B is a small bore tube, called the "shaft," or the "fall-tube." G is a tube leading from near the top of the shaft to the vessel to be exhausted. The tube B terminates within a short distance of the bottom of a vessel D, having a spout F, over the

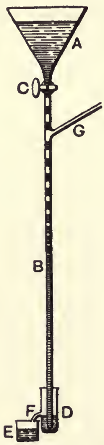


FIG. 45.—Sprengel Pump. Simple Form.

cup E. The length of B from its junction with G to the level of F should be at least three feet. Mercury is poured into A, whence it flows downwards into B. The rate of flow is adjusted by the cock C, so that a very small stream is formed. The result is that air is drawn from G and carried down the tube B. The falling mercury breaks up into short lengths, entrapping small columns of air at the juncture of G and B. The weight of the mercury forces these little columns of air down the shaft B, and they escape at the surface of the mercury in D, while the mercury itself runs out through F into the cup E, from which it is every now and then poured back again into A. This operation

is kept continually going until the mercury ceases to carry down any more air. It then falls into the tube B with a sharp rattling noise, showing that there is not enough air between the drops of the mercury to act as a cushion. It does not, however, follow that because the mercury rattles the vacuum is necessarily good. It will rattle while still taking down small bubbles of air. Similar action to that mentioned in the case of Toepler's pump is also going on here. Some of the air entrapped by the mercury sticks to the fall tube, and the mercury goes down, leaving it behind. If, however, the pump is kept going for some time after it appears to be taking down no more air, the vacuum will be found to improve, showing that the air is gradually swept off the glass.

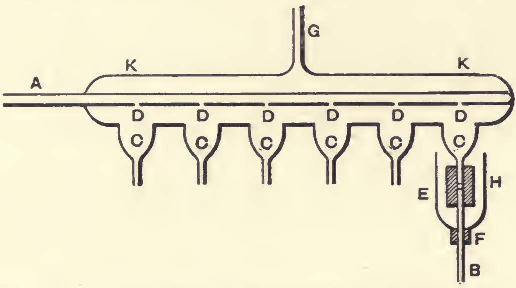


FIG. 46.—Sprengel Pump Distributor for Six Fall Tubes.

This simple form of Sprengel pump, although better than the simple form of Geissler, is not adapted for lamp factory requirements as it stands. One reason is that it is very slow. In order to increase the speed, several fall tubes may be connected together. Thus, if there are six tubes, the time taken to produce a vacuum such that the mercury rattles will be about one-sixth of the time which would be taken by a single tube. From this point, however, the time taken to produce a good vacuum will not be nearly so much reduced. The total time of pumping is, nevertheless, very considerably shortened.

One great trouble with the Sprengel pump is that the fall-tubes crack, often after being only a very short time in use, owing to the continual hammering of the mercury in the tube.

A method of connecting together several fall-tubes is shown in Fig. 46. The tube G, communicating with the lamps, is connected to the upper side of a tube K K, about one inch in

diameter. On the lower side of K are a number of cups or funnels, C C, according to the number of fall-tubes required. Through one end of K passes a smaller tube A, having a small hole D, immediately over each of the funnels C C. The whole of this arrangement is welded together so as to be perfectly air-tight. The fall-tubes may also be welded to the funnel pieces C C, but, as they are always liable to break after a while and, consequently, have to be replaced, it is more convenient to connect them by such an attachment as is shown on the right-hand funnel in the illustration. E is a rubber tube, fitting tightly on the top of the fall-tube B, and on the tail of the funnel C. In order to insure that this connection shall be perfectly air-tight, it is entirely covered up with mercury held in the cup H. This cup is supported by the rubber cork F, fitting tightly between the base of the cup and the fall-tube. The cup and its supporting rubber

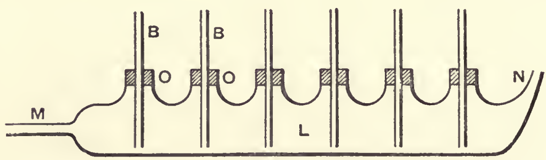


FIG. 47.—Sprengel Pump Collector for Six Fall Tubes.

can be moved up or down the fall-tube, so that the rubber connection E can easily be got at when it is necessary to change a fall-tube. A cracked fall-tube can thus be replaced by a new one in about two minutes. When the pump is at work, the mercury enters through the tube A, and forms a small stream at each of the holes D D. These streams of mercury falling into the funnel pieces C C, carry the air down the fall-tubes in the manner already described.

The fall-tubes may conveniently terminate at the bottom in an arrangement such as shown in Fig. 47. B B are the fall-tubes, which reach nearly to the bottom of the horizontal tube L, into which they pass through the rubber corks O O. The mercury coming down the fall-tubes flows out through M, while the air which it carries down escapes through N.

The method of exhausting into a partial vacuum, as already described in connection with the Giessler form of pump,

can also be applied to the Sprengel pump with the corresponding advantages. The length of the fall-tubes, and, consequently, the height to which the mercury must be lifted, can be very much reduced, while the air is more readily swept down and out of the fall-tubes.

In all the pumps hitherto described it will be noticed that the mercury has to be lifted to the top of the pump by hand. As mercury is very heavy, and the lifting must be kept up continuously, the operation is a very tedious one. Various methods of doing this part of the work mechanically and automatically have, in consequence, been devised, so that the pumps when once started may be left to take care of themselves until a good vacuum is obtained.

The mercury is sometimes pumped up from the lower reservoir to the upper one by an ordinary kind of force-pump, or it is lifted in small buckets running on an endless band, after the manner of a mud dredger.

Mercury should, however, never be directly exposed to the air in the pump room. It should be entirely closed up: firstly, because it will otherwise get dirty; and, secondly, because it is very poisonous when present in the air in a fine state of division or as vapour. Serious cases of mercury poisoning have occurred in pump rooms where the mercury has not been enclosed. As several of the best patterns of pumps of both types entirely enclose the mercury, there is no excuse for this. The floor of the pump-room should be so constructed that any mercury which may be accidently spilt by the breaking of a pump or otherwise can be entirely and quickly gathered up.

The most convenient way of lifting the mercury is by air pressure. It may be accomplished by atmospheric pressure forcing the mercury into an exhausted chamber, where a vacuum is maintained by a mechanical pump driven by power. The limit to the height to which the mercury can be raised in this way, in a continuous column, is, of course, 30in. If the pump is one which requires the mercury to be raised a greater height than this, it may be accomplished by lifting it in several stages. The mercury is first raised to one exhausted chamber, and from that up to a second one by admitting air into the first. In this way it may be lifted to any required height.

Another method is to use compressed air, which, according to the degree of pressure used, can lift the mercury in one stage to any desired height.

Mercury can, however, be lifted into a vacuous chamber to a much greater height than 30in. by atmospheric pressure alone, provided that it is not in a continuous column. The column must be split up into lengths with air spaces between, exactly, in fact, like a Sprengel pump working upwards. The mercury can, in this way, be raised to any height, provided that the sum of the vertical heights of the broken-up columns in the tube does not exceed 30in. This is a slow method, as the diameter of the lifting tubes must necessarily be small in order that the air may drive the plugs of mercury upwards without bubbling through them. The number of lifting-tubes required will be as great as or greater than the number of fall-tubes of the pump.

When pumps are worked by hand, it is impossible for one person to keep more than two or three going at the same time. By automatic methods of raising the mercury, a number can, however, be attended to simultaneously. It is, in fact, essential for the proper working of the lamp factory that some other means than hand power be utilised. The illustration (Fig. 48) shows an arrangement adapted to a Sprengel pump for lifting the mercury by compressed air. The pump is a full-length Sprengel. The lamps are connected to N. The mercury in the vessel K (corresponding to the funnel A, Fig. 45) descends by gravity, through the tube M, into the pump-head A, and down the fall-tubes B into C, carrying, of course, air, drawn from the lamps, with it. The air thus carried down escapes through D, while the mercury falls through E and F, past the valve G, and up into the chamber H. The valve G is capable only of closing the tube below it and not above it. The chamber H is connected, through I, alternately to an air-pump and to the atmosphere.

As the mercury falls, it gradually collects in the chamber H until it nearly fills it, H being open to the atmosphere through I. Air under pressure is then admitted through I, and presses on the mercury, with the result that the valve G closes and the mercury in H is forced up the tube J, and out at the top into K. The pump in the meantime continues working. The

mercury entering C from the fall-tubes flows out through E, and collects in the bulb F and in the tube below. When most of the mercury has been driven from the vessel H up into K, the air pressure is released, and H is again open to the atmosphere through the tube I. The mercury then filling the tube J falls back into H, the reservoir K being open to the atmosphere at the top. The head of mercury in the bulb F will

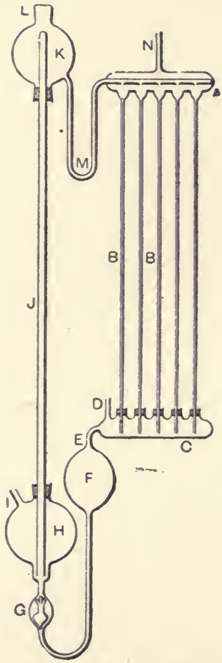


FIG. 48.—Sprengel Pump with Air-Pressure Lift.

now be sufficient to lift the valve G, and it will flow into H. In a few minutes H will again be nearly filled with mercury; air pressure will be applied through I, and a further supply of mercury will be lifted to K. The circulation of mercury is thus constantly maintained, and the pump is kept working continuously.

The air pressure, intermittently applied at I, is carefully maintained at a fixed value, a blow-off valve being

arranged so that it cannot exceed the proper amount. The pressure is such that it can support a column of mercury about 1in. shorter than the tube J; thus it is never able to quite empty H of mercury and blow air up the tube J. The cock for turning the pressure on and off at I may be worked automatically—in fact, it must be if one man is to attend to a number of pumps. One large mercury-lifting apparatus may, however, be arranged to supply a number of pumps.

Fig. 49 shows a similar method applied to the shortened form of Sprengel pump. The mercury is raised, by means of

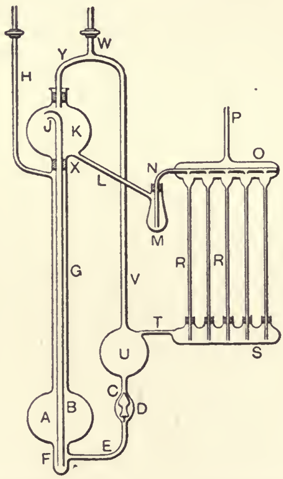


FIG. 49.—Shortened Form of Sprengel Pump.

alternate applications of vacuum and air at the normal pressure, into a vacuous chamber. The fall-tubes R R may be quite short—12in. or 15in. will answer very well. They terminate at the bottom in the chamber S, into which they pass through air-tight rubber corks. The tube T connects S with the top of the bulb U. Below U is a valve chamber D and a valve C. This valve stops the flow of mercury upwards but not downwards. The tube E connects the bottom of the valve-chamber with a tube F, leading into the bottom of the bulb A. The tube G, rising out of A, terminates in the reservoir K. The tube B, inside G, is open at both ends and rises to near the top of K. At X it passes through a rubber cork, which effec-

tually closes the passage from G into K. The tube H connects with G just below the cork X. The tube W has two branches—one branch, Y, enters the reservoir K through an air-tight rubber cork, and the other branch, V, leads to the top of the bulb U. The tube L leads from the bottom of the reservoir K to the vessel M, into which passes the tube N, which carries the mercury into the pump-head O. The lamps are connected to P.

The action of this apparatus is as follows :—The lamps being sealed on and the bulb A being full of mercury, a vacuum, constantly maintained by a mechanical pump, is applied at W, H being open to the air. The first result is that air is drawn out of the whole apparatus, including the lamps connected to P, through the tubes V and Y, and out at W. The mercury in A at the same time tends to rise up into U, and also up the tube B. It is, however, prevented from rising into U by the action of the valve C, and can, therefore, only ascend in the tube B, which it is driven to do by the atmospheric pressure upon it in A, communicated through the outer tube G, which is in connection with the atmosphere through H. The top of the tube B is turned over at J, so that the mercury flowing up is not driven into Y, but is turned aside and falls into the bulb K. From K it runs by gravity into M, and thence up N and down the fall-tubes R R into S, carrying with it air, which it draws from the lamps through P. From S, both the mercury and the air, which it has carried down, rise through the tube T and enter the top of the bulb U. Here the mercury collects and the air passes up through V and out at W. The bulb U is thus gradually filled up with mercury, which is unable to escape downwards, as the valve C is kept up by the pressure below it. This pressure, being somewhat greater than that of the column of mercury in B, is, of course, able to hold up the valve C against the lesser pressure of the head of mercury in U.

When the bulb U is thus nearly filled with mercury and the bulb A is nearly empty, a vacuum, produced by a second mechanical pump, is applied at H. The pressure on the mercury remaining in A is, therefore, removed, and the mercury filling the tube B at that moment falls back into A. The head of mercury in U at the same time causes the valve C to

drop, and the mercury falls by gravity from U through the tube E into the bulb A, the air pressure in U and A being about equal, as both of these chambers are at the reduced pressure of the mechanical vacuum pumps connected to H and W.

The mercury which had collected in U having thus run into A, air at normal pressure is again admitted at H, the valve C again closes, and the mercury is once more driven from A up the tube B into the reservoir K, from which it continues to flow to the fall-tubes.

The action of the cock in H, not shown in the illustration, which turns on alternately vacuum and air at normal pressure, is timed so that a fresh supply of mercury is lifted into K before the previous quantity has all run out into the fall-tubes. The action of the pump is, therefore, continuous. The vessel M forms an air-trap to prevent any air from being carried into N, and so spoiling the vacuum in O.

It will be noticed by comparing the illustrations that the shortened form of Sprengel pump, Fig. 49, is precisely similar to, and works in the same manner as, the long form, Fig. 48. In the long form the mercury is lifted by air *above* atmospheric pressure into a chamber *at* atmospheric pressure, the air drawn from the lamps escaping into the atmosphere direct. In the shortened form the mercury is raised by air *at* atmospheric pressure into a chamber *below* atmospheric pressure, while the air drawn from the lamps escapes through a vacuous chamber.

The length of the tube B, from J to the bottom of the bulb A, should be a little over 30in., so that under no circumstances can air, entering through H, find its way either into K or into the valve chamber D. This is on the supposition that a good mechanical vacuum is maintained at W. The pump may, however, be so much shortened that the full lift of 30in. is not required. The length of the tubes G and J may, therefore, be less, but the vacuum at W must also be correspondingly lower.

The shortened form of Sprengel pump is not exempt from the trouble of the cracking of the fall-tubes. Although the tubes are very much shorter than in the long form, the actual height of the fall of the drops of mercury upon the mercury columns in the tubes is about the same in each case.

Similar methods for lifting the mercury can be applied to the Geissler form of pump. Fig. 50 shows an arrangement by which the mercury is raised by the alternate application of vacuum and air at normal pressure. This form of pump was first used by Mr. Weston. A is the pump bulb, B is a reservoir somewhat larger. These two bulbs are connected by the tube C. D is a cock for drawing off the mercury, if necessary, for cleaning, &c. A mechanical exhaust pump is applied at K, and another one is intermittently applied at E. The lamps

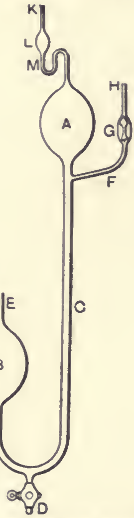


Fig. 50.—Weston Pump.

are connected to H. G is a valve for preventing the mercury rising into H. The pump contains sufficient mercury to fill the bulb B and the tube C to the same height.

In starting the pump, vacuum is applied at both K and E. Air is consequently drawn out of the pump and the lamps. When the mechanical exhaustion has proceeded as far as possible, an automatic arrangement cuts off the vacuum at E and admits air at the normal pressure; the mercury is consequently forced from B into A, sweeping the air in A before it. The mercury will rise to L, about 30in. above the then level in B. Mercury also flows up the tube F as far as the valve G, which prevents it going any higher in that direction.

Vacuum is then again applied at E, and the mercury consequently falls back again from A into B, leaving behind, however, enough to form a seal in the bent tube M. The mercury in the tube F also falls into C, the valve G drops, and connection is again established between the lamps and the bulb A. The cycle is again and again repeated, until a good vacuum is obtained in the lamps.

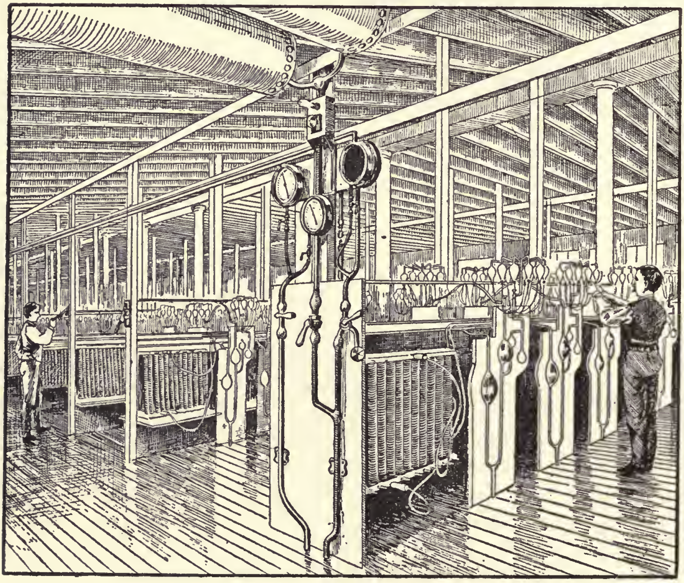


FIG. 51.—Sawyer-Mann Pump Room.

Fig. 51 gives a view of the pump-room of the Sawyer-Mann lamp factory in New York, and is reproduced from the New York *Electrical Review*. It will be noticed that the pumps are of a similar construction to the one just described. In the foreground are seen the gauges for indicating the degree of pressure in the tubes connected to the mechanical pumps. Great care has to be taken that the mechanical pumps are working properly all the time, and the gauges must be constantly watched.

It is not necessary to have a very good vacuum at E, as the mercury is not required to be lowered by 30in. from L. The

height from F to L need not be more than half that amount, so that a vacuum of a little over 15in. will suffice to draw the mercury below F. The pump is, however, sometimes represented with the bulb B only just below the level of A. In this case the vacuum at E must be greater, or the mercury will not descend below F. The distance between M and L must also then be increased, or else the full pressure of the atmosphere must not be admitted at E.

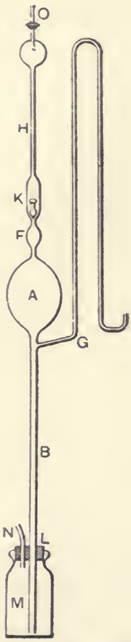


FIG. 52.—Swinburne Pump. Factory Pattern.

Instead of applying alternate vacuum and air at atmospheric pressure at E, alternate applications of air *above* atmospheric pressure and air *at* atmospheric pressure may be used. In this case the bulb B must be situate more than 30in. below F.

For factory use, Mr. Swinburne worked his form of pump in a similar way. Air under pressure was used to raise the mercury. Fig. 52 shows the arrangement. The pump itself

has been already described on page 141. The shaft B passes through a rubber cork L, into the bottle M, to within a very little of the bottom. A tube, N, also passes through the rubber

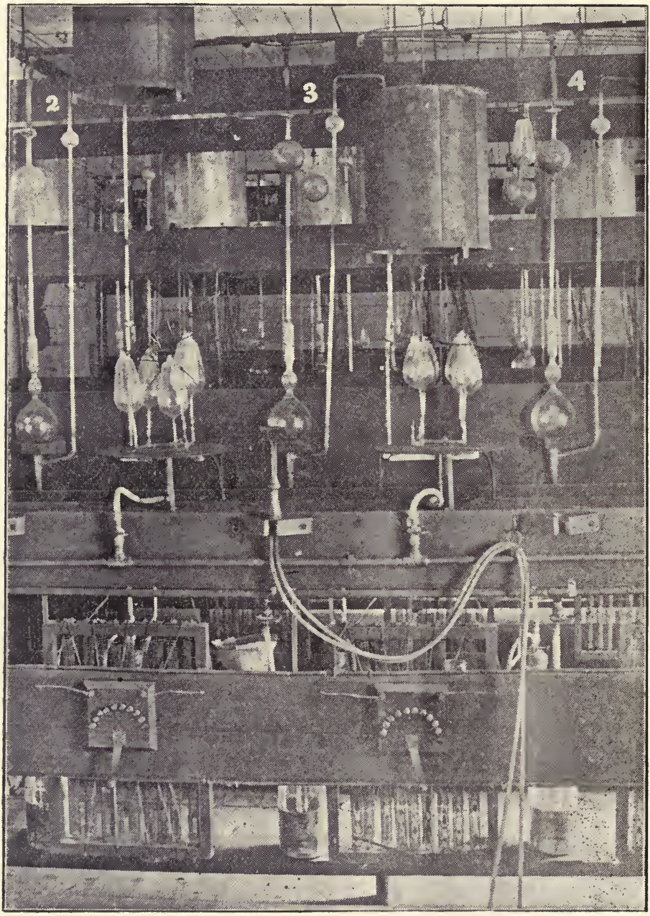


FIG. 53.--View of a Pump-Room with Swinburne Style of Pump.

cork. In starting the pump the cock O is turned, thereby connecting the pump with the mechanical vacuum pump. Air is therefore drawn out of the pump and the lamps, and mercury from the bottle M rises in the shaft B until it forms a column

nearly 30in. high, reaching to a point a little below the junction of the tube G with the shaft B. Air under pressure is then admitted at N. The mercury is consequently forced from M up the shaft B, filling the bulbs A and F, until it reaches the valve chamber K, driving the air before it. At this point, the full air pressure being exerted, the mercury rises no higher. The air pressure required is not great—only about 6lb. or 7lb. to the square inch, representing a rise of the mercury column from G to K of 12in. or 14in. By an automatic arrangement, the pressure is then taken off, the tube N being connected with the outside air. The mercury consequently

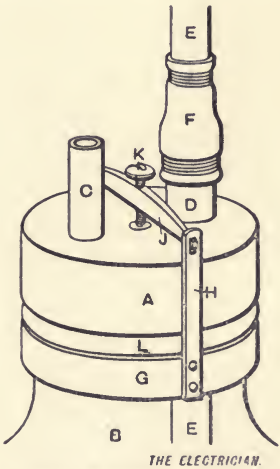


Fig. 54.—Details of Top of Mercury Reservoir of Pumps in Fig. 53.

descends, the valve K closing and remaining sealed, with some mercury left behind in the valve chamber. The mercury drops to below G; the air left in the lamps therefore expands into A, and the operation is again repeated.

Fig. 53 gives a view of part of a pump-room, with this type of pump, erected by the Author. The pumps are of a rather large size, containing nearly 30lb. of mercury each. They differ from that shown in Fig. 52 in some of the details. For instance, instead of the rubber cork L in the reservoir M, the arrangement shown in Fig. 54 was adopted. A is a hard wood cap, fitting the top of the jar B, and having two

metal tubes, C and D, passing through it. These tubes are screwed in so as to be quite air-tight. E is the shaft of the pump, passing through D to the bottom of the jar B. F is a piece of rubber tube, bound tightly with wire round D and E, thereby making an air-tight joint. G is a metal collar round the neck of the jar, immediately under the rim L. H is an upright strip of metal fixed to G, there being another similar one on the farther side. J is a metal cross-bar, extending at each end into slots in the uprights H. K is a screw passing through J. A rubber washer is placed between the cap A and the top of the jar. The screw K is tightened until the cap is pressed down, so that the joint is air-tight. The air pressure pipe is connected to C. This arrangement was found to be much more reliable than the simple rubber cork, owing to the latter not unfrequently working loose and allowing the air to escape.

In the illustration there are four rows of pumps, two rows back to back, with a passage between sufficiently wide to allow of replacing or repairing a pump from behind. The horizontal pipe at the top is the mechanical vacuum pipe, having a branch to each pump. Every pump has a glass stop-cock at the top, by means of which it can be connected to or cut off from the mechanical vacuum pump. The pipe just below the level of the table supplies the gas for heating the lamps. A few inches below this is the air-pressure pipe. Both of these pipes have a branch with a stop-cock for each pump.

Another modification of the Geissler pump adapted for factory work is represented in Fig. 55. It was designed by Mr. Rankin Kennedy, and used at the Woodside Electric Works, Glasgow. It will be seen that this pump is a shortened form of Toepler's pump (p. 138). A is the pump bulb, B the reservoir, Y is a small bore tube leading from the top of the pump bulb into a mercury seal C (corresponding to the tube O M and the mercury seal N, respectively, in Fig. 42).

The arrangement shown is worked by a vacuum, produced by a mechanical pump, applied at K, with alternate applications of vacuum and air at atmospheric pressure at O, in the same manner as in the Weston pump (p. 153). The shaft T passes to nearly the bottom of the reservoir B, and is of such

a length that the height of the pump from the top of the tube Y to the bottom of the bulbous part of the reservoir B is less than 30in., though it is carried downwards into the narrow extension of the reservoir preferably to a greater distance than 30in. from Y, in order that the air pressure may under no circumstances be able to reach the end and blow through.

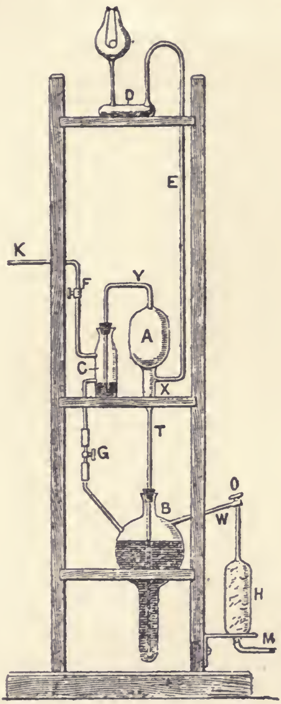


FIG. 55.—Kennedy Pump.

In starting the pump, the mercury being in the reservoir B, as represented in the diagram, a mechanical vacuum is applied through K, by turning the cock F. The cock G is closed and the three-way cock O connects B with the atmosphere. Air is, therefore, drawn from the bulb A and the lamps through the mercury seal C and out at K. The mercury in B rises in T and fills the pump bulb A and overflows into C. The cock O is then turned, cutting off B

from the atmosphere and connecting it to a mechanical vacuum. The pressure being thus removed from the surface of the mercury in B, the mercury descends from A back into B, leaving a Torricellian vacuum in A secured by the seal C. Air from the lamps then expands and fills A, when the cycle is again repeated, the mercury sweeping the air from A past the seal. The excess of mercury which passes into C at each stroke is returned to the reservoir B when under vacuum by opening the cock G.

By increasing the length of the shaft T, so that the height from the point X, where the tube E joins the shaft T, to the bottom of the bulbous part of the reservoir B, is slightly over 30in., this pump may be worked by compressed air and air at atmospheric pressure exactly as described in connection with the Swinburne pump (p. 155). This pump was described in the *Electrical Review*, Vol. XXXIII., p. 391.

Thus far, each different pump, and the way it works, has been described separately. There are, however, certain matters to be considered in connection with the process of exhausting, which apply equally to all forms of pump.

An American lamp-maker likens the process of exhausting air from a bulb to driving flies from a room containing several millions of them. "They leave," he says, "by great droves at first, but the real labour begins when only a few remain. The task is usually called complete when all except the last dozen have found the means of exit." This is not a bad simile. It is the last part of the exhaustion which gives the trouble.

A little calculation upon the Geissler form of pump, with, say, the capacity of the pump bulb equal to that of the lamps being pumped, shows that it should not take very many strokes in order to reduce the amount of air in the lamps to something very close indeed to zero. In practice, however, it takes very considerably longer than the calculation would lead one to expect. The reason of this is twofold. Firstly, the carbon filaments of the lamps occlude gas, which takes time to come out; and, secondly, the air has a way of sticking to the glass, both of the pumps and the lamps. The occluded gases are removed by lighting up the lamps, when the exhaustion has proceeded far enough to make it safe to do so. The current should not be turned on until the vacuum in the

lamps appears to be as good as can be obtained. The filaments are brought to a dull red heat only, at first; and gradually, as the gas driven out is pumped away, they are made brighter and brighter until eventually they are brought up to a state of incandescence equal, at least, to that at which they will be run as finished lamps. When the current is first turned on, it will at once be seen that gas is driven from the filaments by the pump again taking out air. After the full brightness has been reached, the pumping must be continued until the vacuum is again as perfect as possible.

The way in which the current is applied may be seen in Fig. 53. Flexible wires having small hooks or loops on the end are hung on the platinum wires of the lamps. Below the table is seen a resistance and switch for regulating the current. Lighting up the lamps during pumping in this way necessitates, of course, dynamos and engine and boiler power proportional to the number of lamps to be run. As, however, the current is not applied until there is a good vacuum in the lamps, it is best, if possible, to arrange that some of the lamps shall be under current, whilst the others are in the first stages of exhaustion. In this way a smaller generating plant will suffice than would be required if all the lamps were to be lighted at the same time. It is, however, a somewhat difficult matter to arrange this in practice. The question of power is a serious one. If all the lamps are ready for current at about the same time there will be, perhaps, during the day, periods of an hour when no current at all is required, while half an hour afterwards the full power may be called for. This necessitates a large plant and boilers which will make steam very rapidly. If there is not sufficient steam ready when it is required a delay will be caused, which may prevent a whole round of lamps from being finished in time for sealing off before closing time. It is, therefore, much better to use secondary batteries, which can be charged continuously by a much smaller plant than would be required for direct working, the batteries being of a size large enough to supply the whole of the lamps at one time if required.

With regard to the gases which come from the filament when it is thus heated by the current, those which come off at the temperature of red heat, and below, are, no doubt,

rightly termed "occluded"—that is to say, they have been absorbed by the filament since carbonisation. Those, however, which make their appearance when the filaments are bright are more probably products of the more complete carbonisation of the filaments by the high temperature to which they are subjected by the current.

The other action, which prolongs the time required to perfect the vacuum beyond the theoretical period, that of the air sticking to the glass of the pump and the lamps, is more difficult to deal with. This air, which appears to adhere as a film to the glass, will come off gradually, but the process is a very slow one; in order to assist it the lamps are heated during the pumping. It is not, however, an easy matter to heat the pumps, and it is seldom attempted, except in the laboratory. In Fig. 53 a method of heating the lamps can be seen. A metal cover is lowered over the lamps, and a Bunsen gas flame is applied below. The lamps can thus be heated to any desired extent up to the softening points of the glass.

In some factories the lamps are attached to the pumps the other way up, with the glass tube, connecting them with the pump, passing through a hole in the top of the cover. This arrangement is not so good, as the lamps cannot be so well heated when the hot air is allowed to escape through the top of the cover.

When the lamps are heated, the air is driven off the glass and is pumped out. Fortunately for the lamp-maker, the removal of the air film from the pump itself, and from the tube leading to the lamps, is of no very great consequence, for the reason that it takes such a long time to come off. It is not necessary to make elaborate arrangements for heating the pumps. If a pump, being perfectly air-tight and in good order, be worked until no more air is taken out, and be then left to itself for 24 hours, and after that interval be started again, it will be found to again take out air, this air having come off the surface of the glass. It takes some hours for an appreciable quantity of air to accumulate in this way.

Although, then, when the pump ceases to take out any more air, and a film of air is still adhering to the glass, there may be, nevertheless, an exceedingly good vacuum within the

pump and the tubes and the lamps, the lamps themselves, having been heated, do not contain an air film, while the air film on the glass of the pump and the tubes takes a long while getting into the vacuous space. The lamps can, therefore, be sealed off before the air film has had time to come off the glass of the pump and spoil the vacuum. The vacuum in the lamps may, consequently, be just as good as though the pumping had been going on for some days, gradually getting rid of the air film in the pump.

When the lamps are sealed off, air is let into the pump before another lot of lamps is sealed on. On account of this

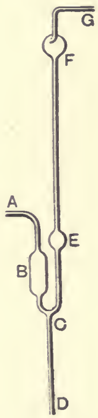


FIG. 56.—Swinburne's Arrangement for Constantly Maintaining a Vacuum in a Pump.

the air film in the pump is renewed with each batch of lamps, and is never got rid of. At the British Association meeting in 1890, Mr. Swinburne described a method for sealing on fresh lamps without letting the full atmospheric pressure of air into the pump. Fig. 56 shows the arrangement. The tube A leads to the lamps, and the tube G to the pump. There is a vessel of mercury in connection with the bottom of the tube D, so that when there is a vacuum in the pump and the lamps there is a column of mercury in D reaching to the point C. When a batch of lamps is sealed off, and another lot is to be sealed on, the mercury reservoir below D is lifted sufficiently to cause the mercury in D to rise and fill the

bulb B, and, to an equal height, the tube E. A cock in the lower part of D is then turned, thereby cutting off communica-cation with the movable mercury reservoir. Air is then let into the apparatus at the point where the lamps are to be sealed on. The result is that the air entering through A drives the mercury from B up the tube E F, where it will stand at the barometrical height above the level in B. The lamps are now sealed on, and are exhausted through a tube connected to A by a mechanical pump. The mercury column in E F therefore descends until it is nearly level with that in B. The connection between A and the mechanical pump is then sealed up, the cock in D is again opened, and the mercury reservoir is lowered. The mercury, therefore, runs out of B and E to about its former height, C, in the tube D. The passage is then open between the new lot of lamps and the pump, which is then set going. In this way the greatest pressure of air at any time allowed within the pump can be kept down to that equal to about half-an-inch of mercury. Such a contrivance would, however, be of little practical use in connection with most forms of pumps, because there is another channel by which the air-film in the pump is continually maintained.

The mercury, in all the pumps described, and parts of the interior of the pumps themselves, are, at intervals, in contact with air either at or above atmospheric pressure. The mercury is forced from these high-pressure parts of the pumps into those parts where the perfect vacuum is required, and from which it is expected to remove all the air. The very mercury itself, however, in its passage through the tubes from the high-pressure to the low-pressure regions, sweeps a film of air along those tubes from the high-pressure parts to the low-pressure chamber. Thus the mercury itself maintains a small supply of air in the very chamber which it is required to exhaust. The amount of air introduced in this way may be, in some forms of pumps, extremely small, but in others it is very perceptible, and, of course, puts a limit to the perfection of vacuum obtainable.

In the case of the Geissler form of pump, either as in Fig. 50 or 52, the action proceeds in this way: When the mercury is filling the pump bulb A, the reservoirs B or M respectively

are nearly empty of mercury, and experience the full air-pressure. As soon as this air-pressure is released the mercury flows back into the reservoir, imprisoning a film of air between itself and the glass walls of the reservoir and (in the case of Fig. 53) the lower end of the pump shaft. When the mercury next flows from the reservoir into the pump it carries part of this film along with it, gradually working it forward. At each stroke of the pump a little of it is delivered into the pump head and a little more is taken in at the bottom of the shaft to be gradually worked in. The amount of air thus introduced is less with the form of pump reservoir shown in Fig. 52 than with that of Fig. 50. In the latter case the film over the whole surface of the reservoir is gradually worked forward, while in the former arrangement only that on the part of the pump shaft which extends into the reservoir can enter the pump, the film on the reservoir itself having no suitable connection with the pump shaft.

In the Sprengel pump (Fig. 48) the same action goes on in the reservoir K. The mercury here, rising and falling, works the air film into the tube M, and so into the pump head. The shortened form of pump (Fig. 49) is, however, much better in this respect. All the while this pump is working there is a vacuum maintained in the reservoir K by a mechanical pump. If this vacuum were always maintained, no air film to speak of could be formed in K; it is, however, lost every time a fresh lot of lamps is put on the pumps, unless a method like Fig. 56 is used. The vacuum in this part would probably be lost in any event during the night when the mechanical pump had ceased working. An air film will thus be formed in K, and gradually work into M. Little of it will, however, find its way into the tube N. The primary object of the trap M N is to catch bubbles of air carried there by the mercury, and prevent them from getting into the pump head, such bubbles being formed by the splashing of the mercury falling from J into the vessel K. It, however, serves the double purpose of stopping the progress of air bubbles, and to a great extent of the air film.

That a film of air really does exist between the mercury and the glass may be readily ascertained by heating the shaft or other tube of a pump containing mercury with a Bunsen gas

flame. As soon as the heat gets through the glass, bubbles appear on the inside, and grow larger and larger as the heating is continued, until they rise through the mercury and escape at the top of the column. If these bubbles were mercury vapour or moisture, they would be condensed in passing up through the cold mercury column, and would not reach the top, whereas they pass up before the upper part of the mercury column is sensibly heated, and escape at the surface.

It is well known that mercurial barometers have to be boiled for a similar reason, in order to expel this air.

A method of overcoming this trouble in the case of the Geissler form of pump has been contemplated by the Author. It consists in enclosing the mercury in the jar or reservoir at the base of the pump in a rubber bag, something like the "bladder" of a foot-ball, the neck of the rubber being tied over the end of the shaft. The mercury would then be raised in the same manner by compressed air, with the difference that the air does not come into contact with the mercury or the end of the shaft. Consequently, after the pump has been worked a few times, and the original air film has been worked out, no further air film can enter by the bottom of the pump, and a method for always keeping a vacuum in the pump, like that in Fig. 56, might be used with advantage. It is possible that by such means a much higher vacuum might be obtained than would otherwise be possible.

The idea of a rubber bag, or diaphragm, used in this kind of way is, however, not new. It was described more than ten years ago in a patent specification by Mr. Stearn in connection with his Sprengel type of pump. Mercury was raised into a vacuous chamber by the pressure of air on the opposite side of a flexible diaphragm, so that the air did not come into actual contact with the mercury. The particular arrangement described is, however, somewhat complicated. The specification says: "Greater uniformity and celerity of action are attained owing to the reduction of the length of the exhausting portion of the pump, and the keeping of the mercury in sealed, exhausted vessels during the periods of its circulation." No mention, however, is made of any arrangement for keeping out the air *between* the periods of the circula-

tion of the mercury—that is to say, when the pump is not working, or when a fresh lot of lamps are being attached.

Stearn appears also to have been the originator of the shortened form of pump.

There is, however, a far more serious trouble than that of the air film to be guarded against in working with mercury pumps. It is that of moisture. Any moisture in the pump will make a good vacuum an impossibility. It will be impossible to obtain an exhaustion of less than the tension of the water vapour, which is so great that the vacuum obtainable is not nearly good enough for a lamp. At the ordinary temperature of the air the pressure is equal to that of about half an inch of mercury. In order, therefore, to keep the pump dry, there is always a "drying tube," containing some substance having a great affinity for water, connected to the pump. This tube is usually inserted between the lamps and the pump, so as to prevent any moisture from the lamps from passing into the pump. Calcium chloride or strong sulphuric acid have been employed as the drying agent, but the only really effective drier is phosphoric anhydride. A tube, or tubes, of this substance (a white powder) are connected, so that the air passing out of the lamps must pass over it. Such a tube may be seen in Fig. 53, just below the stand on which the lamps are resting, and also at D, Fig. 55. The lamps should be as dry as possible before they are sealed to the pump, or the drying tubes will have to be very frequently renewed. Between the drying tube and the pump there should be a small bulb containing glass wool, to prevent any of the powder from being blown round into the pump.

Unfortunately, moisture can, and often does, get into the pumps, and seriously interferes with their working in spite of the drying tubes. It gets in along with the air used for raising the mercury. It is naturally most troublesome in damp weather. It gets worked in in exactly the same manner as the air film already described. The trouble is greatest in pumps where the mercury is raised by compressed air. The Author has tried passing the air over calcium chloride before it enters the pump reservoir. In damp weather a lot of moisture was absorbed in this way, but it did not entirely prevent the entrance of moisture into the pump. Mr. Kennedy appears to

have adopted a similar arrangement. In Fig. 55 the air which enters the reservoir B has first to pass through the drying bulb H. The method of the rubber bag, mentioned on p. 166, might be very useful in keeping out moisture. In the case of hand or other pumps, where the mercury reservoir is itself lifted, air and moisture might be prevented from entering by having the top of the reservoir entirely closed. The reservoir would then require raising 30in. higher than it otherwise would, owing to the absence of air-pressure on the mercury.

The lamps should be joined to the pump by fusion. Rubber and other joints are not to be relied on. In sealing a lamp on to the pump a hand blow-pipe must be used, and on no account must the lamps be blown into in order to blow out the joint, or moisture will be introduced.

When glass tubing is softened by heat it always caves inwards, and it is usual in glass-blowing to blow into the tube in order to prevent the passage from being closed up. After a little practice it is quite easy to seal on lamps without having to blow into them. If, however, it is desired that the joints be blown out, the air contained in the pumps and the lamps themselves can be made to do the work. When the lamps are sufficiently exhausted they are sealed off by melting the narrow part of the stem close to the bulb by means of the pointed blow-pipe flame. The stem of each lamp sealed off is therefore left on the pump. In sealing on fresh lamps only one of these stems is cut off at a time, so that as soon as the new lamp is melted on there is no outlet for the air in the pump and the lamps. The heat of the joint being made warms the air within the apparatus, and the air consequently exerts a pressure within, and blows the softened glass at the joint outwards. With a little practice this can be done with certainty to the required extent each time. If several lamps are exhausted at the same time on each pump, there is a good deal of time lost in sealing on each one separately in this way. It is, therefore, better to cut off the whole of the "fork," to which the lamps are attached, and seal on a fresh one to which the lamps have already been attached. There is then only one joint to be made on each pump, instead of one for each lamp.

In order to do the sealing on easily, it is necessary to have a small and light blow-pipe. Fig. 57 shows one designed by

the Author for the purpose. It is so small that it can be used in places where there is very little room to work. A is the brass barrel about 2in. long, divided by a partition, B, in the centre. A tube, C, is screwed into B, and forms the air nozzle. D is the air-blast pipe, and E is the gas pipe. The air-jet tube, C, can be adjusted by screwing it in or out with a screw-driver by taking off the cap F. The pipes D and E pass through a wooden handle, G, and are connected to the air and gas supply. One of these blow-pipes may be seen in Fig. 53. The rubber air and gas tubes are entirely out of the way, and

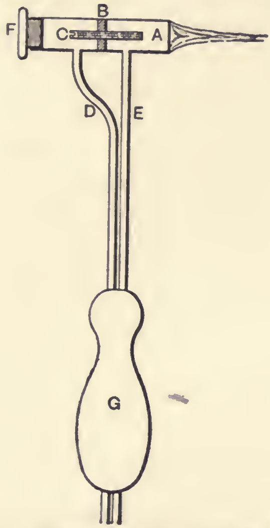


FIG. 57.—Blow-Pipe for Pump-Room.

do not impede the manipulation of the blow-pipe as they do when attached to the barrel in the usual way.

Testing the Vacuum.

It is necessary in the lamp factory to have some means of testing the degree of vacuum in the lamps, both while they are still on the pumps and after they have been sealed off. In the early stages of exhaustion the height of the mercury column in the shaft or fall-tube of the pump will give an indication. When, however, the column has arrived at the height of the barometer, there are still many degrees of exhaustion to

be passed through before the vacuum is good enough for the lamps. It is these higher degrees of vacuum that the lamp-maker requires to test, and for this purpose the height of the mercury column is, of course, no longer of any use.

A gauge was invented some years ago by McLeod for testing these higher degrees of exhaustion, but it is of little use to the lamp-maker. As, however, it is the only gauge by which any estimates of actual pressures can be made, it is here briefly described.

The simple form of the McLeod gauge is represented in Fig. 58. A is a bulb, to the top of which a small closed graduated tube, B, is joined on. A side tube, C, also graduated,

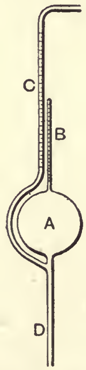


FIG. 58.—McLeod Vacuum Gauge.

is joined on below the bulb. The tube C communicates with the vessel in which the degree of vacuum is to be measured. There is a column of mercury in the tube D, which terminates at the lower end in a movable reservoir. When a vacuum is to be measured, the movable reservoir is raised so that the mercury flows up D into A and B and the side tube C. The mercury rises in A in the same way as in the bulb of a Geissler pump, driving any air contained in A before it into the tube B. As the mercury rises this air is more and more compressed. The mercury, also rising in the open tube C, is at a higher level than that in B, as the air above it is practically unconfined. The difference in the height of the columns C and B is a measure of the pressure upon the air confined in B.

The volume of the air in B is ascertained by the graduations on the tube. The total volume of the bulb A and the tube B, above the point where the tube C branches off, is also known. If this volume be represented by V, and the volume of the air contained in this space when compressed by the mercury into $B = v$, and the pressure indicated by the difference in level of the columns C and $B = P$, and if p equals the pressure of the vacuous space which it is desired to know, then—

$$p = P \times \frac{v}{V}.$$

Measurements of vacua taken with this gauge have been given by various experimenters, showing exhaustions of less than one millionth of an atmosphere. It has, however, been pointed out by Mr. Swinburne that such results do not take into consideration the tension of the mercury vapour, which is stated by some authorities to be as much as 50 millionths of an atmosphere. It is obvious that the gauge is subject to any errors arising from an air film upon the glass. Mr. Swinburne has found that great variations in the readings are caused by a slight heating of the gauge. Such variations might be partly produced by the air film coming off the glass.

Of course, there must be mercury vapour within the pumps, and it probably extends through the often long length (6ft. or 8ft.) of small tubing leading to the lamps. If the pumps and the lamps be at the ordinary temperature of a pump room, say 70°F., and the lamps be sealed off, they will probably be full of mercury vapour and air at the pressure of 50 millionths of an atmosphere, or whatever the pressure of mercury vapour really is at that temperature. If, however, the mercury in the pump is at 70deg., and the lamps be heated to near the softening point of the glass, and are sealed off while at that temperature, they will still be full of mercury vapour and air at the same pressure as before only, though at the very much higher temperature. When the lamps have cooled, the tension of the mercury vapour in them will be very much less than 50 millionths of an atmosphere. It is, therefore, probable that lamps sealed off while hot will have better vacuums* than if sealed off cold.

* In the factory the plural "vacua" is seldom used.

For a similar reason, it would appear wrong to heat the mercury in the pumps. If the mercury and pumps are heated, the vapour will have a still greater tension than 50 millionths of an atmosphere, and the vacuum will be correspondingly poorer, both as regards the mercury vapour and air. If the lamps are sealed off at a lower temperature than that of the mercury, mercury vapour may even be condensed in the lamps. In such a case the lamps would certainly have the full pressure of mercury vapour within them.

The behaviour of the McLeod gauge is of great interest and importance with reference to experiments in high vacua; but how far its indications may be relied upon does not concern the lamp-maker, so far as the ordinary factory operations are concerned. There are other ways, not indeed of testing the actual degree of vacuum, but of ascertaining whether or not it is up to the standard required for the lamp.

The behaviour of the pumps themselves usually gives a sufficient indication. The amount of air being taken out by the mercury at any time can be easily seen in many forms of pumps. In the Geissler form, when there is a narrow tube above the pump bulb, as in Figs. 44 and 50, the amount of air coming out at each stroke can be seen as it passes through this tube. When the vacuum is good, the air-bubble will be very small. When there is no such tube, as in the pumps in Fig. 53, the small air-bubble can be seen as it passes up through the mercury in the valve-chamber, as it invariably passes up against the glass. In the Sprengel pump, when air-bubbles are no longer to be seen coming down the fall-tubes, a good vacuum may generally be relied upon after a sufficient interval from the disappearance of the bubbles. With either type of pump, provided that it is in good order and there are no leaks in the lamps, a good vacuum may, as a rule, be relied upon after the pump has been at work for a certain time, the actual time depending on the particular pattern of pump and the number of lamps connected to it. The time taken to obtain the required degree of vacuum is not, however, directly proportional to the number of lamps on the pump. A pump which will exhaust three lamps in one hour will probably exhaust six lamps in considerably less time than two hours. Up to a certain point the time is approximately proportional to

the number of lamps, but after that point the number of lamps does not make much difference. Up to the time when what might be called the free gases have been removed, the time of pumping is about proportional to the number of lamps on the pump. After that time, when the air-film is being reduced and the gases are being driven out of the filaments, the number of lamps on the pumps does not make much difference to the time required to complete the exhaustion.

After the lamps have been sealed up and removed from the pumps, the vacuum is usually tested by means of an induction spark. An induction coil is fitted up in a dark room or closet, and is arranged so that it would give a spark of about $\frac{3}{8}$in. in length. The terminals are, however, set at a greater distance apart than this, so that no spark passes. The lamp to be tested is then taken in the hand, and its terminals are held against one or other of the secondary terminals of the coil. If the vacuum is very poor, the lamp will glow all through, even before it touches the coil. If it is better than this, however, but still not good, there will be a glow all through the lamp when its terminals touch the coil. If the vacuum is good enough there may still be a considerable amount of glow, but it will all appear upon the inside surface of the glass, and not at all in the interior of the lamp. The glow in the interior of the lamp in the case of a bad vacuum will be of a blue colour, or, if the vacuum is very bad, of a purple colour. In the case of a good vacuum, when there is a glow upon the glass only, it will be blue if the bulb is made of lead glass, but of a green colour if German glass is used. In the case of a good vacuum the glow on the glass is not continuous, but is intermittent, and only appears in patches; or there may be no glow to be seen at all. With a good vacuum, while one hand holds the lamp to one terminal of the coil, the other hand may grasp the other terminal with impunity; whereas, if the vacuum is bad, a shock will be felt.

The coil test is, however, not infallible. A lamp which shows a poor vacuum may, by being run very bright for a minute or two, be made to show a good vacuum on the coil, no trace of any glow being perceptible. Advantage is taken of this phenomenon by pump-room operatives, if not properly looked after, for getting poor vacuums passed as good ones.

The coil test is sometimes applied to the lamps, while still on the pumps, in order to ascertain if they are ready for sealing off. It is more bother than it is worth, however, to do this, as the effect cannot properly be seen except in the dark.

Cleaning the Mercury.

The mercury used in the pumps should be as pure and as clean as possible. The most effective way of ensuring this is to distil it. It may then be freed from other metals, such as zinc, lead, or tin, which it often contains. Mercury that is free, or nearly so, from other metals may be extremely dirty, and absolutely unfit for use in the pumps. In this case it can usually be effectively cleaned by filtering. A piece of blotting paper may be folded and put in a glass funnel, as in filtering any ordinary liquid. A small pin-hole must, however, be made at the bottom. The mercury runs through this hole in a fine stream, and as it descends in the funnel it leaves the dirt which was floating on its surface adhering to the blotting paper. If it is very dirty it may be advantageous to filter it into a vessel containing strong sulphuric acid. It must afterwards be filtered into water, and again into a dry vessel. The most unpromising looking mercury may, in this way, be made quite clean.

Mercury may be distilled in an iron retort at its normal boiling point. It is, however, better to distil it in a glass apparatus under a vacuum, so that it distils over at a much lower temperature, and its progress can be watched. Various forms of apparatus for distilling mercury in this way have been described. That shown in Fig. 59 will answer the purpose. A is a flattened bulb on the end of the tube B. The lower end of B reaches to near the bottom of the open vessel C. The tube E E leads out of A, and is carried down 12in. or so below C. F is a stop-cock communicating with E. The dirty mercury is poured into C, and as it is distilled it collects in G.

To start the apparatus, mercury is poured into C, and a cup of distilled mercury is held to the lower end of E. The cock F, connecting with a mechanical vacuum pump, is opened, and a vacuum is produced in A. The dirty mercury, therefore, rises in B and into A, and the clean mercury rises to a similar

height in the tube E. D is a ring gas burner surrounding the tube B, just below the vessel A. The gas is now lighted, and heats the mercury in A. After a while the mercury in A begins to distil over, the vapour condensing in the tube E. When the distillation is fairly set going, the cock F may be turned off, although it may be necessary occasionally to open it if the vacuum deteriorates from any cause. With a good mechanical pump the level of the mercury in A will be nearly 30in. above that in C, and the level in E a little below F will be an equal height above the bend in the

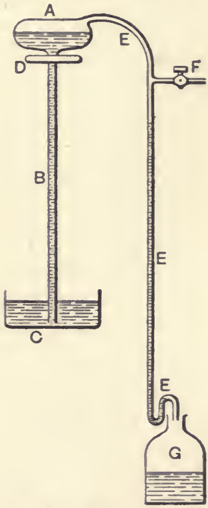


Fig. 59.—Mercury Still.

lower part of E. The depth of the vessel C is such that if it is filled with mercury the mercury in A will not rise high enough to flow into E and foul that which has distilled over. The level of the mercury in A must be watched, so that it does not fall too low. As it distils over, more mercury must be added to C. If the vessel C is a large flat one, it will need less attention than if it is a narrow one, as the level of the mercury in A will be less affected for a given amount distilled over.

Great care must be taken that the mercury poured into C is quite dry. If it is wet or damp, the moisture will get into the

tube B. The mercury in B is hot for some distance below A. In the upper part it is above the boiling point of water. Any moisture is gradually worked into the tube B, and when it reaches the hot part, it is turned into steam and rises into A, and drives the hot mercury in A down into B, so that it reaches the cold part of the tube, and cracks it all to pieces. There should be wire gauze between A and the burner, so as to distribute the heat. A should also have an asbestos cover, so that the mercury vapour is not condensed until it enters E.

Mechanical Pumps.

The process of exhausting lamps with mercury pumps is costly and slow. Any mechanical pump which could quickly and with certainty produce a sufficiently good vacuum would be welcomed by lamp-makers. The difficulties in the way of constructing such a pump are many. One great difficulty is that of preventing leakage through the glands and past the piston. Another trouble is that the working parts require lubrication. If oil is used, there will certainly be vapours given off, which will prevent a good vacuum from being obtained. A pump was exhibited in Boston, U.S.A., about three years ago, in which all the difficulties were stated to have been overcome. It was said to exhaust lamps in a far less number of seconds than a mercury pump would do in minutes. The chief point about this pump was that the working cylinder was enclosed in a vacuum jacket, and in this way all leakage into the working cylinder was prevented. Oil was, however, used in the pump. As nothing appears to have been published regarding this pump since it was first exhibited, it is to be presumed that its performance did not after all come up to the expectations of the inventors.

An ingenious mechanical pump, containing mercury in the cylinder, was patented in 1882 by Gimingham, but the Author does not know to what extent it was found to answer. A hollow plunger, open at the bottom, is caused to work up and down in a cylinder, which is about two-thirds full of mercury. A tube passes through the centre of the bottom of the cylinder to a point about three parts up the cylinder. The lower end of this tube is connected to the vessel to be exhausted, while a valve rests upon its upper end within

the cylinder. There is also a valve in the upper part of the plunger, the two valves being connected by a string. When the plunger is down, it is entirely filled with mercury. On its being raised, a vacuum is produced above the mercury, and air from the vessel to be exhausted is drawn in through the inner tube, the valve being automatically raised by the string. On the plunger being again depressed the lower valve is closed by means of a spring, and the entrapped air is forced through the plunger valve, which remains sealed by some of the mercury which passes through behind the air.

A rotary mercurial air-pump was described by Dr. F. Schulze-Berge in a Paper read before the International Electrical Congress at Chicago, 1893. This class of pump has to contend with the troubles of sliding connections, which must be formed in such a way as to be absolutely air-tight; the alternative being that the vessel which is required to be exhausted must rotate with the pump. Good results, however, appear to have been obtained with a sliding connection.

Pumps for producing the vacua for working the mercury pumps and for flashing, &c., do not require to be of any very special construction. The valves must, however, be opened and closed by direct mechanical action, and should not depend on the pressure of the air. Silk valves will not answer, as they wear out much too quickly, and are not suitable for large pumps.

CHAPTER XIII.

TESTING.

The lamps, having been exhausted, are next tested for voltage and candle-power, and for this purpose it is necessary to have a photometer and instruments for measuring the current and the pressure. The object of the test is to find at what voltage the lamps must be run in order that they shall be at the right temperature—the temperature, that is, at which they are required to be run, 3, 3½, 4, or other number of watts per candle-power as desired.

In some factories only a few lamps are tested on the photometer, and the other lamps are compared directly by eye with these. Thus, if 100-volt lamps are being made, lamps will be selected by the photometer which run at the required temperature at, say, 94, 96, 98, 100, 102, 104, and 106 volts. These seven lamps are all hung up in a line. The lamps to be tested are lighted up on the same circuit, and in close proximity to the standards. They are then labelled according as they are found to compare with the standards.

This is not, however, a satisfactory method of testing. The eyes of the tester soon become unreliable, and refuse to see considerable differences in the temperature of the filaments. Darkened glasses may be used to save the eyes from the injurious effects of continually looking at the bright filaments, but they do not make the testing any easier.

Far greater accuracy can be obtained by testing each lamp separately on the photometer. Those accustomed to make photometric tests of lamps in the laboratory will, perhaps, think that it would be impracticable to test every individual lamp owing to the time occupied in making the test. A

photometer can, however, be arranged for the lamp factory so that the testing can be done very quickly. A thousand lamps a day can easily be tested on one photometer, provided that the lamps do not differ greatly from each other; that is to say, that 100 volt and 70 volt, or 8-c.p. and 20-c.p. lamps are not all mixed up together. In the laboratory the testing apparatus is conveniently arranged for the observer to be able to read the photometer and the different instruments without moving from his seat; but in the factory, for rapid testing, the apparatus is arranged so as to be operated by two or three persons. A wattmeter is also required in addition to the other instruments. A wattmeter is not a necessity in the laboratory, as the calculations can be done on a slide rule with sufficient rapidity; but it is essential for factory testing, as it does away with the necessity for making any calculations whatever.

The great trouble in all photometric measurements is the want of a really good standard of light. The light of the incandescent lamp is estimated in candles. Standard candles are, however, of absolutely no use for factory lamp testing, and are of little value as standards under any circumstances.

The most reliable standard of light is the Harcourt pentane lamp (second pattern). It is simply a lamp burning the vapour of standard quality pentane. It is arranged so that the same size of flame, giving a light of one or two average standard candles, is always presented to the photometer. It is, however, more of a laboratory standard than one fitted for constant use with the factory photometer.

For actual use in the factory an Argand burner, burning ordinary illuminating gas with a Methven screen, is preferable, as it requires less attention. The chief trouble in using an Argand burner, even with a Methven screen, is due to the flickering to which the flame is liable if there is the slightest draught. This can, however, be remedied by enclosing the burner in a large box having openings sufficient only for the proper supply of air to the flame. The Methven screen, it is well known, is simply a metal screen with a hole in it of such a size as to allow only a small piece of the centre of the flame to throw any light into the photometer, the light from this piece of the flame being very much more constant than is that of the whole flame.

The position of the Methven Argand standard is adjusted by comparison with the Harcourt standard, and can be checked by it as often as is thought necessary. If the lamp factory has a separate laboratory, with a photometer and testing instruments, it is more convenient to test a lamp in the laboratory, using the Harcourt standard, and then to give the same lamp to the testers in the factory testing room, and see if their test of it agrees with the laboratory one. A convenient way of keeping a check on the testing is to keep one or two lamps to be always tested first whenever the photometer is used. As long as these standardised lamps always test the same it may safely be assumed that the whole apparatus is in good order.

As regards the photometer itself, the Bunsen type is the most convenient. The ordinary grease-spot may be used, or what is known as the Leeson disc. The former answers very well, but the latter is preferred by some testers. The Leeson disc is composed of a piece of cardboard, having a star-shaped hole cut out of it, and is covered with a thin sheet of paper on each side. Whichever disc is used, it is placed in a small box so as to be in a direct line between the two lights, to be compared with its plane at right angles to such line. One side is therefore illuminated by the standard light, and the other by the lamp under test. A mirror is fixed on each side of the disc at an angle so that the observer sitting in a direct line with the plane of the disc can simultaneously see both sides of it reflected in the mirrors. When one side of the disc is more powerfully illuminated than the other, the grease spot, or the star, whichever is used, will appear darker on that side than the rest of the disc, while on the side less illuminated it will appear brighter. When both sides are equally illuminated, the grease spot, if the disc be a good one, will be almost entirely invisible. When comparing lights of different colour, it will never disappear altogether, but a correct balance can, nevertheless, be obtained by increasing and diminishing the intensity of the illumination on one side of the disc to an extent which is seen to be definitely above and below the balance, and gradually obtaining a mean between the two readings.

The disc should be mounted in such a way that it can be easily reversed. The side which is presented to the gas light

after a while sometimes turns yellow, and ceases to give correct indications; a check should, therefore, be kept upon it by reversing its position and ascertaining if it gives the same reading each way. A new disc should also be carefully tested.

In testing gas or other lights produced by combustion it is necessary that both the lights, the standard and the one under test, be fixed. The photometer disc must, therefore, be movable between the one and the other and, as a consequence, the observer has to stand up and move with the disc. Fortunately for those who have to test incandescent lamps, matters can be so arranged that it is not necessary for them to stand up and crane their necks all day. The incandescent lamp may be moved and the photometer disc may be fixed. The observer can, therefore, sit comfortably in a chair while testing.

It is not intended here to go into the matter of photometry and light standards generally, as there are already works upon the subject. An excellent one is that by Mr. W. J. Dibdin, entitled "Practical Photometry," which, although it deals chiefly with gas-testing, contains much information, useful to the incandescent electric lamp tester.

In testing incandescent lamps the object, as already mentioned, is to find what difference of potential must be applied at the terminals of the lamp in order that it may be maintained at a definite temperature or efficiency in watts per candle-power. It is therefore necessary to light up the lamp and ascertain the amount of power it is taking, and then see if it is giving the required amount of light for that amount of power. If the lamps are to be run at 4 watts per candle-power, then for every 4 watts supplied to the lamp it should give a light of one candle. If the lamp when lighted up is found not to give as much light as one candle for every four watts, or is found to give more than that amount, then it must be run brighter or duller by applying a greater or less difference of potential until it attains the required degree of brilliancy. When the adjustment is found to be correct the voltmeter indication is read, and the number of volts registered is the proper voltage for that lamp.

This system of testing, which was introduced by Mr. Swinburne, is the only correct one. It is obvious that if the lamps are tested at a fixed voltage or candle-power they will vary in

brightness and efficiency (watts per candle-power) unless they are exactly alike in every particular, whereas by this method they are tested at a fixed brightness and efficiency, and the voltage and candle-power are assigned in accordance therewith.

The way in which the Author recommends the use of this method in the lamp factory will now be described.

The photometer table is at such a height above the floor that the lamp and the photometer disc are on a level with the eyes of the observer when sitting comfortably in a chair. The gas lamp with its Methven screen and the disc box are at the right hand end of the table, the lamp under test being on the left hand of the observer. The photometer bar is graduated directly in candles, the zero point being immediately below the disc. The candle-power graduations are proportional to the square of their distance from the zero line.

The lamp is carried in a frame which can be moved to and fro along the photometer bar by the observer at the disc. The lamp holder is also capable of being raised or lowered and rotated. There is also fixed to this frame another bar, also divided into candles, but having its zero mark at the lamp end. This bar slides backwards and forwards with the lamp frame, and the observer at the photometer is therefore able to read the candle-power of the lamp by the indication on this bar at the zero line immediately below the disc, and does not have to look along the bar to where the lamp happens to be in order to get the reading. This is a great convenience, as the observer does not get the light of the lamp into his eyes, as is the case in the former method.

The wattmeter is fixed on a shelf just behind and above the disc box, so that its indications can be readily seen by the observer at the disc, the scale of the instrument being an upright one, and not one which has to be looked down upon. The wattmeter scale is preferably divided directly in candles at four or other number of watts to the candle; or there may be several scales, one above the other, for testing at 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, &c., watts per candle.

There is a large screen all round the disc box, so that the observer at the disc does not see any light except that upon the disc. No light, either from the lamp under test or the

gas lamp, can fall upon his eyes. The wattmeter scale is illuminated sufficiently by a small incandescent lamp run very dull. The scale of candles on the movable photometer bar, being large and on a white ground, can be read by the small amount of diffused light from the lamp under test. In this way there is no light which can upset the eye of the observer.

The switch and variable resistance for adjusting the current, as well as the handle for moving the lamp to and fro, are fixed in a convenient situation for being worked by the observer. The voltmeter (and ammeter, if used) is situated on the other side of the screen surrounding the observer, and is read by one of the assistants. The method of working is as follows:

The tester-in-chief sits at the photometer. In this position he can see the disc box, the wattmeter scale above it, and the candle-power scale below it. He does not see either the lamp under test or the standard gas burner, nor the voltmeter or ammeter, but he has the control of current and of the motion of the frame containing the lamp under test. There are two assistants on the left hand of the tester, one on each side of the photometer table. Before being brought into the photometer room the lamps have each had a small label stuck upon the neck.

Assistant No. 1 now puts a lamp into the clip or holder in the movable carrier. If the lamps are supposed to be 16-c.p. ones the tester sets the lamp at the distance for 16 c.p. by the scale in front of him. He then turns the current on, and brings it up until there is a balance upon the screen. He then looks up at the wattmeter scale to see how many candles the lamp should be giving for the amount of power it is taking. If the wattmeter indicates 16 candles, he tells assistant No. 1 to read the voltmeter, and, whatever the number of volts happens to be, that is the voltage of the lamp.

Supposing, however, when the lamp is giving 16 candles that the wattmeter indicates, say, a little over 17 candles. The lamp in such a case must then be run brighter until its actual candle-power agrees with the indication of the wattmeter. As the lamp is made brighter, there is, of course, more power spent in the filament, and consequently the wattmeter indication also rises, but as the light increases

much faster than the power, the actual amount of light will agree with the wattmeter indication at about 18 candles. The balance being obtained, the voltmeter is read by assistant No. 1. The current is turned off the lamp, and assistant No. 2 takes it out of the holder and writes the voltage on the label, while assistant No. 1 puts the next lamp into position. If the candle-power is also to be marked on the label the assistant can ascertain its value for himself by noting the position of the lamp carrier on the fixed candle-power scale.

As most electrical measuring instruments take a perceptible amount of time to come to rest after the current is turned on, it is necessary for rapid testing that the instruments be not allowed to return to zero between the testing of each lamp. For this reason, instead of turning the current off the whole apparatus it is simply switched off the lamp just tested to another lamp of similar size located in a convenient place for giving light to the assistant testers for writing the labels and fixing the new lamp in position. The next lamp being in position, the current is switched back again, and the instruments quickly arrive at their readings, and do not oscillate as they would if they had started from zero. The instruments must, of course, be so constructed that they may be left continuously in circuit without their accuracy being impaired by heating.

The photometer room is necessarily quite dark, and painted a dead black so as not to reflect light. It should, however, be of ample size. It is absurd to locate the testing apparatus in a room in which there is hardly space to turn round, as is frequently done. It is also advisable to arrange for proper ventilation. It is not necessary, in order to keep out daylight, that the room should be hermetically sealed after the manner of the ordinary photographer's dark room.

The tester should be in the dark room for at least ten minutes before testing, in order that his eyes may get accustomed to the subdued light. On no account should he look at the lamp while testing, or his eye will be unreliable for some time afterwards. There may, however, be a piece of dark neutral-tinted glass in the screen on either side, so that he can see the lamp and the flame of the Argand burner without any danger of his eyes being effected. The Argand burner must be lighted ten minutes or more before it is required, as

it may not give the proper amount of light until the chimney and other surroundings are at the normal working temperature.

Great care should be taken with the measuring instruments to see that they are correctly calibrated and can be relied upon all over their scales.

In measuring the power taken by a lamp with an ammeter and voltmeter certain precautions are necessary. If the voltmeter is connected directly to the lamp terminals, so as to indicate the volts on the lamp, the ammeter must of necessity be connected so as to measure the current through the lamp plus that through the voltmeter. On the other hand, if the ammeter is connected so as to measure the current of the lamp only, the voltmeter must be connected to measure the difference of potential over the lamp plus the ammeter. In the former case there will be an appreciable error, unless the voltmeter has a very high resistance compared with that of the lamp ; and in the latter case there will be an error unless the resistance of the ammeter is so small as to be negligible in comparison with that of the lamp. Instruments can be made of such resistances that in either method of connecting the error is negligible.

A wattmeter may be regarded as a combination of a voltmeter and an ammeter, and is therefore liable to error from the same causes. The resistances of the wattmeter cannot, however, be well made of such amounts that the error is negligible, and it therefore becomes necessary to compensate for the error. This may be done by means of a double winding on the current coil, each winding having the same number of turns. The pressure coil of the wattmeter is connected directly to the terminals of the lamp. The lamp current, plus the current through the pressure coil, therefore, passes through the main winding on the current coil of the wattmeter. The current through the pressure coil alone is, however, taken through the supplementary winding on the current coil in the reverse direction. The current of the pressure coil thus traverses the current coil an equal number of times in opposite directions, and its effect is therefore neutralised, and the instrument gives a correct reading of the power spent in the lamp. In order that the wattmeter shall have as wide a range

as possible, the current coil may be again wound in two equal windings, which can, by means of a switch, be connected up either in series or parallel. This arrangement necessitates the compensating winding being wound in two sections in the same way. There are, therefore, really four windings on the current coil.

Fig. 60 is a diagram of the connections. P is the watt meter pressure coil, C C the main current coil, and K K the compensating current coil. The two parts of these coils can be respectively connected in series or parallel by the switches S_3 and S_4. L is the lamp under test, and l is the subsidiary lamp, which is switched on by the switch S_2 for the

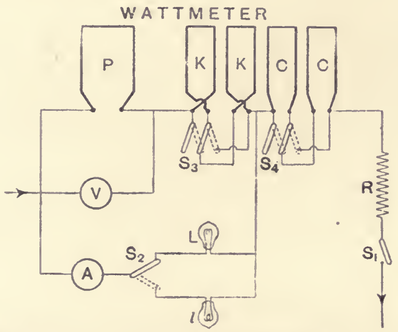


FIG. 60.—Electrical Connections for Testing Lamps on Photometer.

purpose already explained when the lamp L is being changed. R is the variable resistance, and S_1 is the main switch. V is the voltmeter, and A the ammeter. It will be noticed that the voltmeter current, as well as that through the pressure coil of the wattmeter, passes through both the windings of the current coil of the wattmeter, and its effect is therefore neutralised.

If an ammeter is used it may be placed where it is shown in the diagram, provided that it has a resistance extremely small compared with that of the lamp under test. If, however, its resistance is not very small, it must be connected so as to take the whole of the current, including that of the voltmeter and the wattmeter pressure coil. In this case it should have a double winding, precisely as the current coil of

the wattmeter, so that it indicates only the current through the lamp. The resistance of the coils K K is negligible.

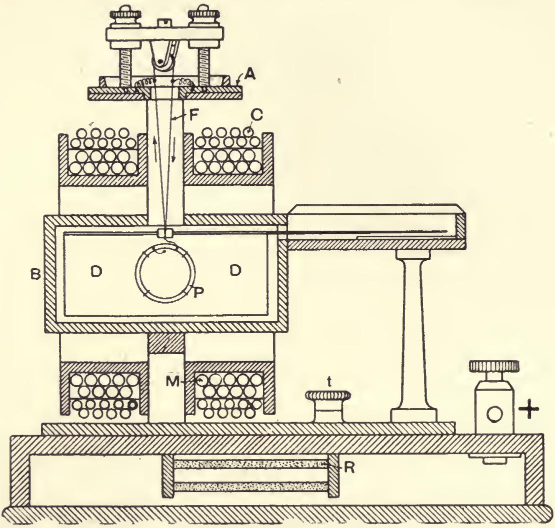


FIG. 61.—Evershed's Wattmeter for Lamp Testing. Sectional Elevation. (For reference letters *see* Fig. 63.)

In a wattmeter constructed by the Author on the above lines most of the high resistance wire was wound on the suspended coil, which was consequently heavy, and required a vane moving in glycerine in order to damp its oscillations.

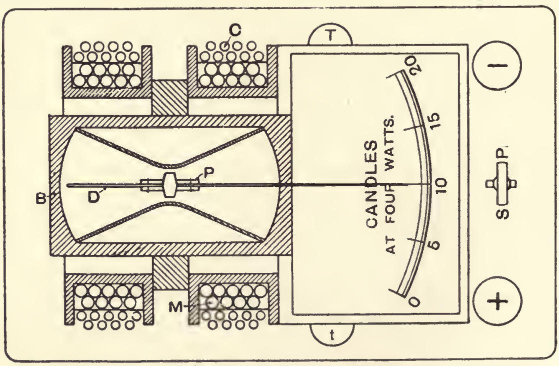


FIG. 62.—Evershed's Wattmeter for Lamp Testing. Sectional Plan. (For reference letters *see* Fig. 63.)

Mr. Evershed has designed a wattmeter for lamp testing of a more delicate construction, the suspended coil being very much lighter than in the instrument the Author has used. By the courtesy of Mr. Evershed the Author is able to give the accompanying sketches of the instrument (Figs. 61 and 62). Fig. 63 is a diagram of the connections, which are similar to those in Fig. 60. There are two small pressure coils P P, one on each side of an aluminium vane D. This vane fits the vane box B only very loosely, but it is so large and light that the air damps out the oscillations in about two seconds. The

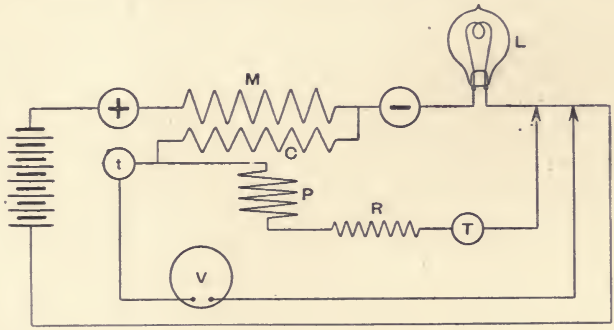


FIG. 63.—Diagram of Connections of Evershed's Wattmeter.

+ −, Main Terminals; T, Terminal of "Pressure" Coil Circuit; t, Terminal for Voltmeter; M, Main "Current" Coils; C, Compensating Coil for Pressure Coil and Voltmeter Current; P, Pressure Coils in Series with Platinoid Resistance R; DB, Vane Box for Damping Oscillations; D, Aluminium Vane, to which P P is fixed; F, Bifilar Suspension, serves to lead Current into P P; A, Plate carrying Pulley and capable of Rotation to adjust Zero; I, Index; S P, Switch to couple M M and C C in Series or in Parallel and obtain double range; V, Voltmeter for Measuring Pressure on Lamp Terminals; L, Lamp under Test.

bifilar suspension F passes over a pulley at the top, and in this way it is ensured that the strain is equally divided. The suspension is silk where it passes over the pulley, but just below the pulley it is wire, and serves to convey the current to the coils P P. Fine wires lead the current to and from the suspension wires at their junction with the silk. In series with the pressure coils P P is a platinoid resistance, R, situate in the base of the instrument. M is the main current coil, and C is the compensating coil for the current through the pressure coil and the voltmeter. T is the terminal of the pressure coil circuit, t is the terminal for the voltmeter. The

main terminals are marked + and −. A is a plate carrying the pulley, and is capable of rotation for adjusting the zero. S P is a switch for coupling the coils M M and C C respectively in series or in parallel, and so obtaining a double range. V is the voltmeter, and L is the lamp under test. I is the index of the instrument. This arrangement of the index and scale is not good for rapid testing in the manner already described, as the observer at the photometer has to turn away from the photometer in order to read the instrument, which must be placed on one side so that he can look down upon it.

The method of compensating the wattmeter and ammeter for the error due to the voltmeter current was devised by Mr. Swinburne.

For laboratory testing, where speed is not so important, it is sufficient to test with an ammeter and voltmeter only. The ammeter, if of an appreciable resistance, should be connected so as to measure the current through the lamp plus the voltmeter current. A table of the voltmeter current for each volt can be hung up in a convenient place, and the amount can be deducted from the ammeter reading at once.

The term candle-power of an incandescent lamp is generally understood to denote the mean horizontal candle-power, and not the mean spherical candle-power.

If the filament of the lamp is circular, a single measurement on the photometer is enough to obtain a reading sufficiently close to the mean horizontal candle-power, provided that the measurement is not taken in the plane of the loop, and that the two sides of the filament are at a considerable distance apart compared with their diameter.

If the filament is not circular, the mean horizontal candle-power can be obtained by taking the mean of a number of measurements all round the lamp, or the lamp may be rapidly rotated while the test is being made.

The mean horizontal candle-power is the candle-power which would be given by a straight circular filament of the same length and circumference.

In the case of rectangular filaments, of which the width and thickness are known, the mean horizontal candle-power can be ascertained by taking the measurement of the candle-power

with the flat side of the filament towards the photometer, and multiplying by a constant.

If w = width of the filament and t = thickness of the filament, the value of the constant will be $0{\cdot}64\left(1+\frac{t}{w}\right)$. If $w = 1{\cdot}77\ t$, then the flat measurement is also the mean.

If many lamps with the same ratio of width to thickness have to be tested, a more convenient plan is to move the standard burner closer to or further from the photometer disc, so that, when measuring the lamp flatways, the mean candle-power is read directly on the photometer scale.

If the ratio of width to thickness be not known, a measurement may be taken with the broad side of the filament towards the photometer, and another at right angles to it with the narrow side towards the photometer. If the candle-power in the former position = W and in the latter = T, then the mean candle-power will be 0·64 (W + T), provided that one side of the filament does not screen the other in making the test.

The direction of the minimum light from a flat filament is at right angles to the thin edge. The direction of the maximum light, however, is not that at right angles to the flat side, but at right angles to a line taken diagonally across the filament from opposite corners.

In testing flat filament lamps it is possible, by turning the lamp, to find the position of maximum and minimum light. If the ratio of the width to the thickness be not known, the mean candle-power can, nevertheless, be found by a single measurement on the photometer. The lamp under test must be rotated until it is seen, by looking at the photometer disc, that it is in the position in which it gives the maximum reading. Let this maximum candle-power = H. The lamp is then turned through an angle β, until it is seen that it is in the position of minimum candle-power. The mean candle-power is then equal to

$$0{\cdot}64\ \mathrm{H}(\sin\beta + \cos\beta).$$

The most accurate method of obtaining the mean horizontal candle-power is probably that of rapidly spinning the lamp, as the regularity of the shape of the filament does not matter.

In various tests which have been published from time to time readings have been taken at every 30deg. all round the

lamp. This gives a mean value sufficiently close to the real one for most purposes, though in the case of flat filaments the mean value obtained in this way may vary 3 per cent., according to the position of the filament—that is to say, whether the flat side of the filament is set towards the photometer at angles of 0deg., 30deg., 60deg., &c., or 15deg., 45deg., 75deg., &c. In the former case the mean of the readings will be about 2 per cent. below the real mean, and in the latter case about 1 per cent. above. Such differences as these are, perhaps, hardly worth troubling about, except in the case of special tests.

Before the lamps are tested they should be thoroughly cleaned. A dirty bulb will obscure the light very materially. After testing they must be sorted out according to their voltage. If they are loop lamps, they are finished except as to final cleaning and wrapping in paper. The cleaning is best done by wiping them with soft paper, first wet and then dry. This is much more effective than using a cloth. When finally cleaned, the lamps should not again be touched with the hand, or finger-marks will be left upon the glass.

CHAPTER XIV.

CAPPING.

If the lamps are to be capped the capping should be done after they have been tested. Lamps are fitted with caps for the purpose of providing a convenient and simple means of securely attaching them to a holder, and making the necessary electrical connections.

The most usual form of cap in this country consists of a short length of brass tube which fits over the neck of the lamp and encloses the platinum wires. The platinum wires are usually soldered to copper wires, which in turn are soldered to the metal contact plates of the cap. The cap is filled up with some kind of plaster, which holds it to the lamp and secures the contact plates. There are pins on each side of the brass tube for securing the cap in the bayonet slot of the holder. There are numbers of different forms of caps designed to fit various patterns of holders. While it is not intended to discuss the merits of the different varieties, there are still a few points to be mentioned in connection with caps generally.

Plaster-of-paris is generally used to fill up the space in the caps. The end of the lamp, as already explained in the chapter on "Sealing-In," is formed in such a way that the plaster will have a firm hold upon it. Different samples of plaster-of-paris are found to vary very much. Some will set much more quickly and become much harder than others. Good plaster-of-paris sets quickly and expands in setting. The expansion in setting of some samples will swell the brass tube of the cap to such an extent that it will no longer go into the holder if it was of a fairly close fit before the plaster was

put in. The addition of slaked lime to the plaster will, however, reduce or prevent the expansion, according to the proportion used, which must be regulated by the quality of the plaster. The Author has also found that the addition of a small percentage of dextrine to the plaster-of-paris makes it very much harder.

Another plaster sometimes used in caps is made of litharge, which is made into a paste with glycerine. This plaster, which sets very hard, is very heavy and more expensive than the plaster-of-paris.

Current should never be put on the lamps until the plaster is quite dry. Plaster-of-paris takes at least four days to dry spontaneously. If the lamp is lighted before the plaster is dry a perceptible amount of current will pass through the plaster in the cap, and one of the copper wires will be electrolised. The Author has known cases where the fine copper wire has been eaten through and the connection with the lamp destroyed in this way. Plaster-of-paris can, however, be easily dried by heat, so that in a couple of hours' time after mixing it will conduct no current. Resin should be used as a flux for soldering the wires to the contact plates. When a lamp holder is discovered to be very hot, as is sometimes found to be the case, the heating is often caused by a current passing though the plaster of the cap, but is generally and often erroneously attributed to a bad contact between the holder and the cap. The trouble is sometimes due to the too abundant use of an acid flux in soldering, the excess remaining in the plaster.

CHAPTER XV.

EFFICIENCY AND DURATION.

The Author has adhered to the expression "watts per candle-power" in preference to that of "candles per watt," as, although the latter is the more correct, the former has the advantage of being the one generally adopted, doubtless because it is more convenient. It is easier to quickly grasp the meaning of a certain number of watts, and perhaps a fraction added, than of a particular fraction of a candle-power.

It will be readily understood from what has already been said that no lamp can be said to be *of* or to *have* a greater or less efficiency than another. One lamp may be run at a greater efficiency than another, and may then be said to be *at* a greater efficiency, but it possesses in itself no greater efficiency, as the second lamp can be equally well run at the higher efficiency.

The higher state of efficiency simply means that the filament is at a higher temperature. Any lamp may be run at any efficiency or temperature up to its breaking point. With incandescent carbon a certain temperature means a certain colour of light and a definite efficiency, either in watts per candle-power or in proportion of luminous radiation to total radiation. Whether the same thing can be said of all incandescent substances does not yet appear to be definitely settled. Certain of the metallic oxides may, perhaps, prove exceptions. The well-known Welsbach gas burner seems to suggest such an exception, but the Author does not know of any tests upon this point. Certainly, to the unaided eye, the colour of the light of a Welsbach mantle is absolutely different from that of a gas flame, though the temperature of the particles of carbon

in a gas flame might be supposed to be much the same as that of the Welsbach mantle. Certainly neither can be hotter than the gas flame. Possibly, however, the particles of carbon are very far below the temperature of the flame. These particles of carbon have a very great emissivity, and may, perhaps, radiate heat and light so fast that they never approach the actual temperature produced by the combustion of the gas. On the other hand, the Welsbach mantle, having a vastly inferior emissivity, is raised nearly to the actual temperature of the flame. The emissivity of the Welsbach mantle is extremely low. One which the Author measured gave when new less than eight candles per square inch of surface. The carbon in a gas flame gives many times this amount of light per square inch. Accurate tests with a spectro-photometer might settle this question. If the material of the Welsbach mantle is only at the same temperature as the carbon particles in a gas flame, then it must have the property of selective radiation, and may, therefore, be found to have a greater light-giving efficiency than carbon.

In the case of using such oxides as the light-giving portion in electric lamps, one thing is apparent: that the extent of radiating surface will have to be very much greater than that of a carbon filament for the same amount of light if at the same temperature.

The only way to ascertain the relative superiority of different incandescent lamps is to run them all at a constant pressure and all at the same efficiency at the start. They must then be tested at periods of, say, fifty hours at the same pressure as the original test, in order to find the diminution in candle-power. Such tests might be called "deterioration" tests. Thus, a lamp losing 10 per cent. in candle-power in 400 hours is a better lamp than one losing that amount in 300 hours.

Life tests, pure and simple, are worthless. A great many carefully-ascertained life tests of different lamps have at various times been reported. Such tests are, however, of no value unless the actual tests of candle-power of the lamp at different periods of its life are also given. It is also equally necessary to know within what limits the difference of potential was maintained throughout the run, as well as the length of time during which it was above or below the normal.

All lamps fall off in candle-power when supplied with a constant number of watts. Lamps usually fall off in candle-power from the commencement of their active life, when supplied with current at a constant pressure. The deterioration in this case is, however, sometimes masked during the first hundred hours or so by the resistance of the filament falling. A greater amount of power is therefore supplied to the lamp, which may, in consequence, give even more light after a hundred hours than it did at the first. Such behaviour is, however, the exception rather than the rule, and seldom occurs in flashed lamps.

What amount of deterioration should be allowed before a lamp is cast aside it is difficult to say, and depends upon the circumstances of each individual case. As long as a lamp gives sufficient light in its particular situation there is no need to change it. A new lamp may be fixed over a writing table, and after a hundred hours may be found to be no longer bright enough; it is therefore taken down, but it will do perfectly well in some other situation—say, in a bedroom or passage—for a further and longer period. The price of the lamp determines as much as anything the period at which it is thrown away. The cost of a candle-power hour for the actual amount of light given increases as the light of the lamp diminishes. In order that the total cost of maintaining a given amount of light may be a minimum, it is necessary to renew the lamps at certain definite times. The length of time each lamp is used depends in such case upon the price of the lamp, the price of the power, and the rate of deterioration of the lamp. As the last of these conditions is variable even with lamps of the same make, it is impossible to fix the period under any conditions of price of lamps and power. Lamps in ordinary use cannot be tested every fifty hours, and it, therefore, happens that they remain in use as long as they give light enough.

The length of time taken by lamps of the same make to deteriorate in candle-power by a certain percentage depends very much on their treatment. If the pressure is maintained constant, say within 2 per cent. on either side of the normal, the useful life will be longer than if the pressure is allowed to vary by 5 per cent. The pressure at which electricity is

supplied by central stations is anything but constant. The very best supplies are not to be relied upon to keep within 5 per cent. on either side of the normal, while some extensive supply systems do not keep within 10 per cent. The alternating systems seem to be more difficult to regulate than the direct current. Deterioration tests of lamps of the same make on the

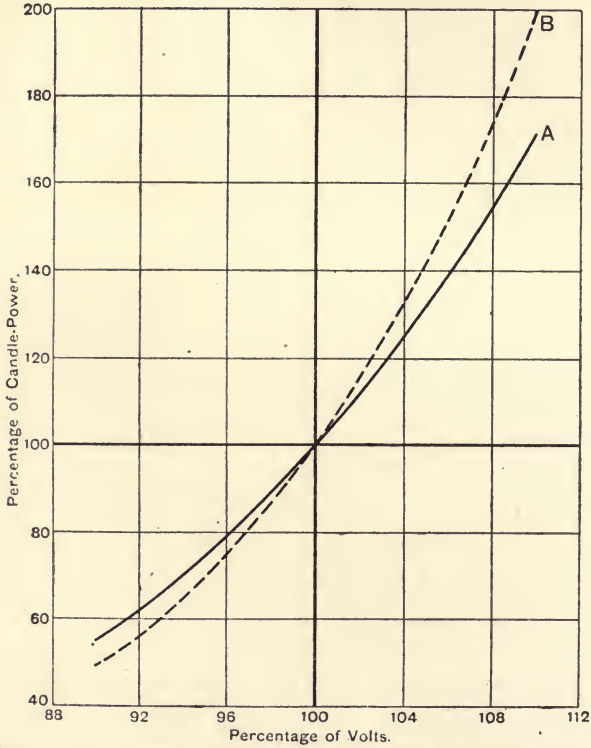


Fig. 64.—Curve showing Percentage of Normal Candle-Power at any given Percentage of the Normal Volts.

different supply systems would be very interesting and instructive, and would go far towards settling the dispute as to the relative merits of the various systems in use.

In order to show the importance of the constancy of the pressure, Fig. 64 is given. It shows approximately the percentage variation in candle-power for any given percentage

variation in the volts over a range of 10 per cent. above and below the normal. It will be found to be about correct whatever be the temperature or efficiency of the lamp at normal voltage. The curve A gives the results when the filament is constant in resistance over the range of 10 per cent. in volts. The dotted curve B gives the result if the filament uniformly falls off in resistance by 5 per cent. for an increase of 10 per cent. in the volts—that is to say, the resistance falls 1 per cent. for a 2 per cent. rise in volts, or 2 per cent. for a 4 per cent. rise, &c. As a rule the values lie nearer B than A. It will be seen that a slight increase in the pressure causes the candle-power to rise greatly, while a slight decrease means a great falling off in the light.

The falling off in the candle-power of lamps is due to particles of carbon being thrown off the filaments. This action reduces the light of the lamp in three ways. Firstly, the particles of carbon form a coating on the glass of the lamp, and, therefore, obscure the light given by the filament. Secondly, the nature of the surface of the filament is altered, and its emissivity is increased so that it is at a lower temperature. Thirdly, the resistance of the filament is increased, so that it takes less current, and is again, on this account, at a still lower temperature. Thus, not only does the filament give less light, but a great proportion of what it does give is prevented from getting outside the bulb. In order to find out what proportion of the total loss of candle-power might be due to these different causes the Author made the following somewhat extreme test:—

A lamp was tested at about 2 watts per candle-power. It took 51·7 volts and gave 55 candle-power for a consumption of 107·7 watts. It was then run at that voltage until it was much blackened, and it was then tested again. At 51·7 volts it gave only 12 candles, and, owing to rise in resistance, it took only 100 watts. The total loss of candle-power was, therefore, $55 - 12 = 43$, or 78 per cent. In order to find out how this loss was made up, the filament was taken out of the blackened bulb and put into a new one. The air was then exhausted to the same degree as before, showing a very good vacuum by the spark test. The lamp was then again tested. At 51·7 volts it took 100 watts, and gave 30 candles. It was

then run a little brighter, so as to take the original power of 107·7 watts, and it gave 42 candles and took 52·8 volts. The loss of light due to the blackened bulb was, therefore, 30 − 12 = 18 candles = 60 per cent.

The loss due to increase in emissivity is given by the decrease in candle-power, when the same amount of power was supplied to the filament. The loss due to change in emissivity is, therefore, 55 − 42 = 13 candles = 23·6 per cent.

The loss due to change in resistance is given by the difference in candle-power when the filament was supplied with the original number of watts, and when supplied with the original number of volts; because, had the resistance not gone up, the original number of volts would have given also the original number of watts. The loss due to increased resistance is, therefore, 42 − 30 = 12 candles in 55 = 21·8 per cent. The rise in resistance is about 8 per cent. The loss due to change in emissivity, plus that due to change in resistance, therefore = 13 + 12 = 25 candles = 45·5 per cent.

This result is also shown by the difference between the original candle-power and that at the original volts when the filament is in the new bulb, *i.e.*, 55 − 30 = 25 candles. It is, therefore, apparent that the filament at the original volts gives 25 c.p. less than it gave at first: it gives only 30 candles, or 54·5 per cent. of its original candle-power.

We have already seen that the blackened glass obstructs 60 per cent. of the light of the filament; therefore, of this 54·5 per cent. of light given by the filament 60 per cent. is stopped by the blackened bulb.

60 per cent. of 54·5 per cent. = 32·6 per cent. The total reduction in the light of the lamp is therefore made up in the following way:—

Less light given by filament, owing to	Candles.	Per cent.
(1) Increase in emissivity	13	23·6
(2) ,, resistance	12	21·8
Total (1) and (2)	25	45·4
(3) Stopped by blackened glass............	18	32·6
Total reduction	43	78·0

The greater part of the decrease in the light of the lamp is, therefore, owing to the filament giving less light. Of that which it does give only a part gets through the blackened bulb.

Though the above test is perhaps an extreme one, the lamp having been very much overrun, the same kind of result undoubtedly occurs in lamps run at ordinary temperatures.

The black deposit on the bulb of a lamp stops not only much of the light radiation, but also much of the heat. The result is that a blackened lamp often gets extremely hot.

The effect of a fall in the resistance of a lamp is strikingly shown in the following test:—An unflashed lamp had just been tested at 50 volts. It gave 12·5 candles, and took 0·82 ampere, and, therefore, 41 watts, and its resistance was 61 ohms. It was then accidentally run for an instant at 100 volts. The testing was being done on a 100-volt circuit, and the resistance in series with the lamp was momentarily short-circuited. The bulb was in consequence blackened, and the filament had lost its shiny appearance. It was, therefore, expected that a great diminution in candle-power would be observed at 50 volts. The resistance of the filament had, however, been so much reduced as to more than counteract the dulling effects. The lamp tested 50 volts, 1·03 ampere, 22 c.p., and, therefore, 51·5 watts and 48·5 ohms. The resistance had gone down 20 per cent., so that the lamp took so much more power than it did at the first that the increase in emissivity, which undoubtedly occurred, was not sufficient to prevent a great increase in the temperature of the filament; and the blackening of the bulb, though great, was also not sufficient to mask the effect of the great increase in the light given by the filament.

If a filament could be found whose resistance gradually fell as its emissivity increased and the bulb blackened, a lamp of uniform candle-power or of uniform watts per candle-power throughout its life might be possible. Such a lamp would not have so long a life as one of which the resistance increases, but it would have a more useful life, and would automatically end its career at the proper time. Unfortunately, the filaments which are usually found to fall in resistance do so during the first part of their life, when they should remain constant; and when they should be going down they increase.

CHAPTER XVI.

RELATION BETWEEN LIGHT AND POWER.

It has already been stated that the light given out by an incandescent filament increases at a much greater rate than the power spent in the filament. The relation of the light to the power, or to the pressure or the current, has been the subject of much study and speculation. Many and various formulæ have been given by different investigators. Some of them are nearly correct when applied to certain lamps, but are found to be quite useless when applied to others. No formula yet given appears to satisfy all cases. The reason probably lies in the imperfections of the lamps. The filaments of different lamps vary in their behaviour at different temperatures, and the vacuums also vary.

In 1882 Prof. A. Jamieson showed that the candle-power of incandescent lamps was approximately proportional to the sixth power of the pressure, and, therefore, to the sixth power of the current, since the resistance of the filament when incandescent does not alter much.

The most recently published tests have been carried out, under the direction of Prof. Ayrton, at the Central Institution of the City and Guilds of London, and were published in part in *The Electrician* of July 15, 1892. These tests are valuable, as they appear to have been carried out with great care to eliminate various errors, and the observations were made by three observers.

It is shown by these tests that there is a definite relation between the logarithms of the candle-power and of the volts, amperes, or watts respectively of each lamp. As, however, the tests referred to are not carried above the temperature

of about 4 watts per candle-power, the Author introduces here some tests which he has made up to a much higher temperature.

Lamp B.						Lamp D.					
C.P.	Volts.	Amps	Watts.	Ohms	$a\,V^n$	C.P.	Volts.	Amps	Watts.	Ohms	$a\,V^n$
5·3	29·0	1·13	32·6	25·7	5·15	2·0	30·0	1·03	30·9	29·1	2·33
6·2	30·0	1·15	34·5	26·1	6·2	3·0	32·0	1·1	35·2	29·1	3·22
8·8	32·5	1·23	40·0	26·4	9·52	4·0	33·0	1·15	37·9	28·7	3·92
10·6	33·0	1·28	42·2	25·8	10·3	5·0	34·5	1·2	41·4	28·8	5·05
12·5	34·0	1·31	44·5	26·0	12·07	6·0	36·0	1·24	44·7	29·0	6·34
14·2	35·0	1·34	46·9	26·1	14·18	7·0	37·0	1·27	47·0	29·2	7·4
16·0	36·0	1·36	48·9	26·5	16·4	8·0	37·5	1·3	48·7	28·9	7·97
17·7	36·5	1·39	50·7	26·3	17·65	9·0	38·0	1·33	50·5	28·6	8·5
22·2	38·0	1·45	55·1	26·2	22·0	10·0	39·0	1·36	53·0	28·7	10·0
26·5	39·5	1·49	58·8	26·5	26·8	12·5	40·2	1·4	56·3	28·7	11·68
35·4	42·0	1·58	66·4	26·6	37·4	15·0	41·8	1·45	60·5	28·6	14·5
44·0	43·5	1·66	72·1	26·2	45·0	20·0	43·7	1·51	66·0	29·0	18·4
53·0	45·0	1·7	76·5	26·4	51·4	25·0	45·5	1·58	72·0	28·8	24·0
62·0	46·0	1·75	80·5	26·4	61·3	30·0	47·0	1·62	76·3	29·0	27·6
71·0	46·8	1·78	83·5	26·4	66·8	35·0	48·5	1·68	81·5	28·9	32·6
80·0	47·8	1·81	86·5	26·4	74·6	45·0	51·2	1·77	90·5	28·9	44·2
106·0	50·5	1·9	96·0	26·6	100·0	50·0	52·2	1·85	94·5	28·2	48·9
124·0	52·0	1·94	101·0	26·8	117·8	60·0	54·2	1·88	102·0	27·8	60·7
142·0	53·0	1·98	105·0	26·8	130·0	70·0	55·4	1·92	106·2	28·8	68·0
159·0	55·0	2·05	112·8	26·8	159·0	80·0	57·0	1·98	113·0	28·8	80·0
177·0	56·0	2·07	116·0	27·0	174·5	90·0	57·8	2·01	116·3	28·8	86·5
195·0	58·0	2·13	123·6	27·2	210·0	100·0	59·6	2·08	124·0	28·8	102·0
212·0	60·0	2·2	132·0	27·3	252·0	120·0	62·0	2·17	134·5	28·6	127·0
230·0	61·8	2·22	137·2	27·8	296·0	140·0	64·8	2·25	145·0	28·8	166·0
248·0	65·0	2·3	149·5	28·3	389·0	160·0	68·0	2·35	160·0	28·4	211·0
...	...	...	...	...	...	180·0	69·0	2·38	164·0	28·9	230·0
...	...	...	...	...	...	200·0	72·5	2·49	181·0	29·1	300·0
...	...	...	...	...	...	250·0	80·0	2·7	216·0	29·6	518·0
...	...	...	...	...	...	295·0	90·0	2·8	252·0	32·2	1000·0

The lamps B, C, D, are of Edison-Swan manufacture, and lamp A is an unflashed amyloid filament lamp. The tests of A and C were, however, not carried very far.

Fig. 65 shows the curves of watts and candle-power up to about 2 watts per candle-power, and Fig. 66 shows the results of lamps B and D run up to their breaking points. The dotted lines show the watts per candle-power.

It will be noticed that both the curves (Fig. 66) turn over at the higher readings. This is caused by the disintegration of the filament and its consequent change in emissivity and resistance, and by the blackening of the bulb. The direction of the curves above the point where rapid disintegration begins depends, among other things, upon the length of time during

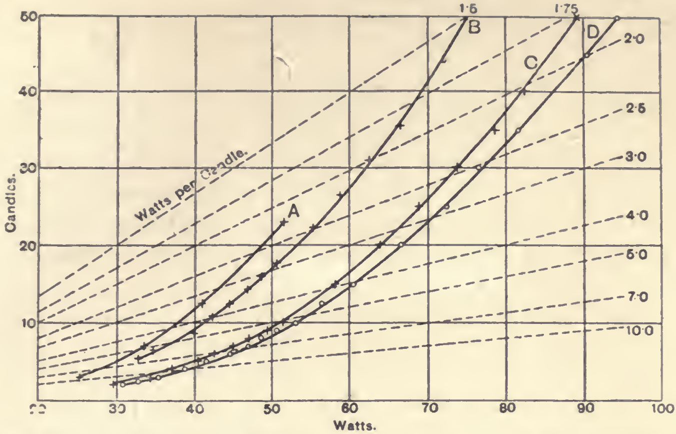


FIG. 65.—Curves showing Relation of Candle-Power and Watts for Four Lamps, A, B, C, D.

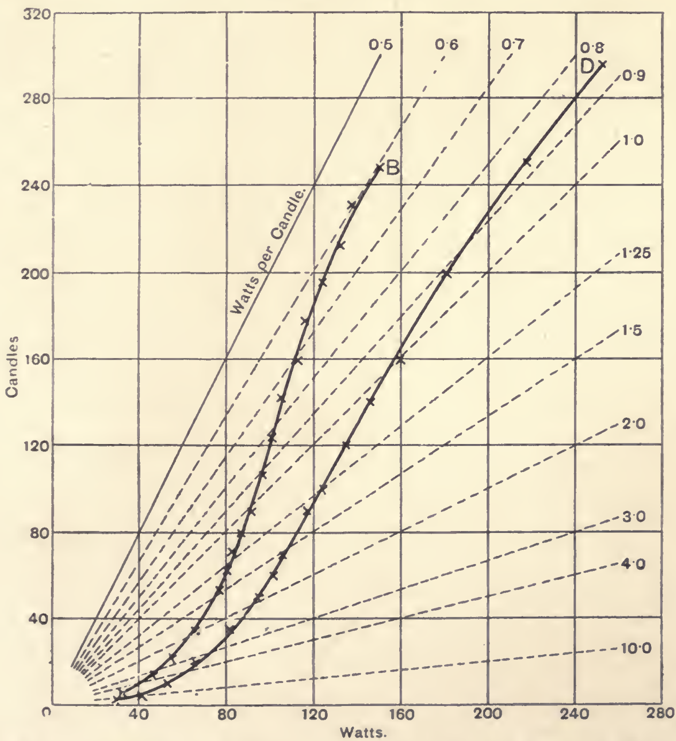


FIG. 66.—Curves showing Relation of Candle-Power and Watts for Lamps B and D, up to their Breaking Points.

which the lamp is kept at each temperature while the observations are being made. The curve of a lamp which is kept at 1 watt per candle-power for some time may, for instance, be made to bend over so much that it will never reach 0·9 watt per candle-power, as the lamp will break before arriving there. It will be seen that lamp B attains a much higher efficiency than lamp D. The observations at the higher readings in each case were, however, made as quickly as possible.

Fig. 67 shows the relation between the logarithms of the candle-power and of the volts and watts respectively. Up to the point where the lamp begins to rapidly deteriorate it will be noticed that the observations in this figure lie nearly in straight lines—sufficiently so to suggest that they ought to be exactly in straight lines. Assuming that to be the case, the expression $\text{C.P.} = a\,\text{V}^n$, where C.P. = candle-power and V = volts, a and n being constants, would enable us to find the candle-power at any voltage when the values of a and n are known.

In order to find the value of a and n for any lamp, two observations at least must be made.

If c.p. = candle-power at the lower reading,
,, v = volts ,, ,, ,,
,, C.P. = candle-power ,, higher ,,
,, V = volts ,, ,, ,,

then
$$n = \frac{\log \frac{\text{C.P.}}{\text{c.p.}}}{\log \frac{\text{V}}{v}},$$

and
$$a = \frac{\text{c.p.}}{v^n} = \frac{\text{C.P.}}{\text{V}^n}.$$

The observations from which the value of a and n are obtained must be made with the greatest care, and should be as wide apart as possible. A very slight error in the test will give a wrong value to the exponent n, and will make the calculated results quite wrong.

In the case of lamp B, taking the readings of 30 volts 6·2 c.p., and 55 volts 159 c.p., the value of n is found to be 5·35 and $a = 7{\cdot}76 \times 10^{-8}$.

In the same way for lamp D, at 39 volts 10 c.p. and 57 volts 80 c.p., $n = 5{\cdot}51$ and $a = 1{\cdot}695 \times 10^{-8}$.

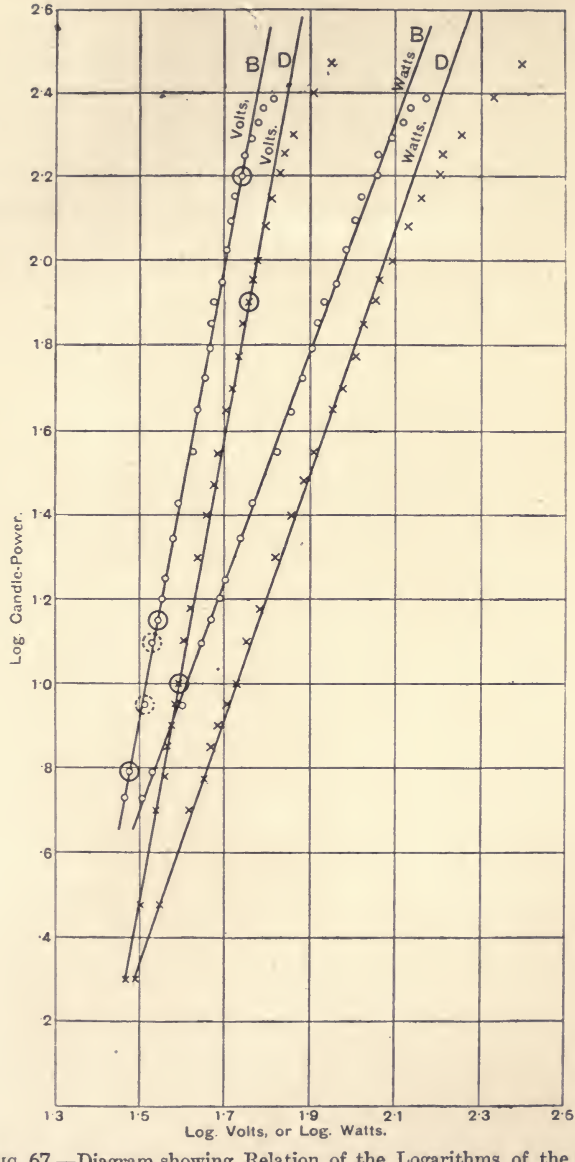


FIG. 67.—Diagram showing Relation of the Logarithms of the Candle-Powers to the Logarithms of the Volts and of the Watts respectively of Lamps B and D.

In Figs. 68 and 69 the dotted curves show the values calculated on the above basis. The crosses mark the observed values. Over the lower portion of the curves the observed and the calculated values lie very close together. In Fig. 69 it will be seen that the curve B, representing the actual observations, definitely takes a different direction from B′, representing the calculated values at about 180 c.p., or at an efficiency

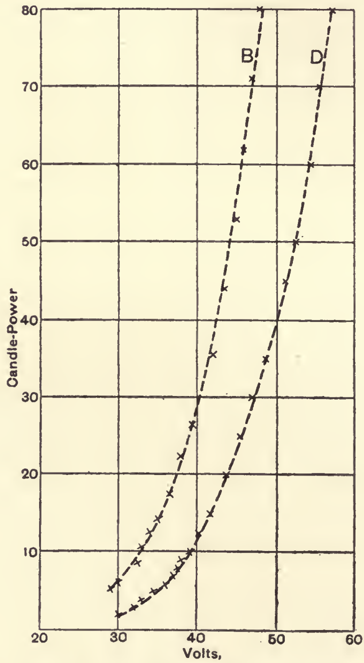


Fig. 68.—Lower Part of Curves of Candle-Power and Volts for Lamps B and D.

of 0·65 watt per candle. The curve D separates from D′ at 100 candles, corresponding to an efficiency of 1·25 watts per candle-power only. This would seem to show that lamp D was an inferior one to lamp B.

That great care is necessary in making the tests for a and n can be seen in the case of lamp B. If two observations only were made, and these were, say, those at 30 volts 6·2 c.p. and

35 volts 14·2 c.p., the value of n would come out at 5·38, which is very nearly right, these two observations lying almost exactly on the straight line in Fig. 66. If, however, the tests were those of 32·5 volts 8·8 c.p., and 34 volts 12·5 c.p., the one reading of candle-power being a little low and the other a

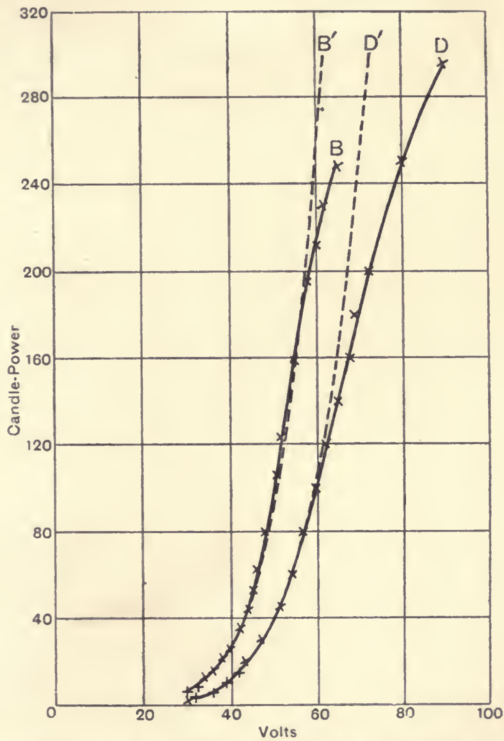


Fig. 69.—Curves of Candle-Power and Volts for Lamps B and D up to their Breaking Points.

little high, the value of n would be 7·9, and the calculated results would be quite wrong, these two observations lying one a little above and the other a little below the line in Fig. 67, where they are indicated by the dotted circles, while the observations from which the correct values are obtained are shown by the full circles.

It is probable that the relation of candle-power to watts is a more constant one among different lamps than that of candle-power to volts or amperes. In the latter case the degree of constancy of the resistance of the filament throughout the range of the test has an effect upon the form of the curve, whereas in the former case it has no such effect.

Throughout this work the Author has adopted the efficiency of 4 watts per candle-power as the standard. This efficiency may be regarded as the highest ordinarily met with in lamps in actual use. At 4 watts a lamp looks bright as compared with a gas-flame. Although lamps are sold marked at 3·5 and 3, or even a less number of watts per candle, they very soon arrive at 4 watts when in use. The mean efficiency of any number of lamps in actual use in any installation, other than quite a new one, is probably quite as low as 5 watts per candle-power.

At a temperature of 4 watts per candle-power, it has been estimated, by actual experiment, that the proportion of luminous radiation to total radiation in an incandescent lamp is about 5 per cent. only, while the proportion in the case of the arc lamp is about 10 per cent. In Fig. 66 it will be noticed that, by running lamp B up to its breaking point, an efficiency of 0·6 watt per candle-power is attained, equal to nearly seven times greater than at 4 watts per candle-power. It might, therefore, be expected that the proportion of luminous radiation to total radiation at this temperature was seven times that at 4 watts per candle-power, or 35 per cent., which would be far greater than that of the arc lamp. This, however, is not at all the case. The candle-power is in no way a measure of the energy of the luminous radiation when comparing lights of different colours. Although by increasing its temperature we get an enormously increased efficiency as regards candle-power per watt expended in the filament, the ratio of the luminous energy to the total energy of radiation does not increase at anything like the same rate. The increasingly refrangible rays, which are produced as the temperature is raised, add little to the light as measured by the photometer, while they require comparatively a large amount of power for their production. Even under the

extreme conditions of 0·6 watt per candle-power the proportion of luminous radiation to total radiation of the incandescent lamp probably falls short of that attained in the arc lamp.

The ideal lamp is one from which the radiation is wholly luminous. The carbon incandescent lamp is, therefore, very far indeed from attaining the ideal standard. A more efficient lamp must evidently be looked for in another direction. The beautiful experiments shown by Mr. Nikola Tesla would seem to point to a direction in which it may possibly be found, but, as yet, illumination by means of vacuum tubes has not reached the efficiency of the incandescent lamp, and is far behind it in point of practicability.

In the preceding pages the Author has not touched upon the History of the Incandescent Lamp or the labours of the men to whom the world is indebted for bringing it to a state of perfection such that it has become an article of everyday use. In the first rank of these are the names of Swan, Edison, Weston, and Lane-Fox ; while following them come a host of others, who have materially assisted in making the lamp what it is to-day. In a book of this size it would be impossible to give credit to each for his share in the work, even if it could be ascertained. The manufacture of the incandescent lamp involves so many and various problems, and there have been so many workers in the field, that many inventions in connection with it have been independently made by different individuals.

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